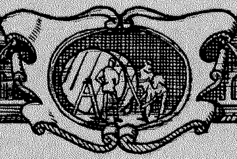

ELECTRICAL COMMUNICATION

1941

VOL. 20 No. 1

ELECTRICAL COMMUNICATION

A Journal of Progress in the Telephone, Telegraph and Radio Art

H. T. Kohlhaas, Editor

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Published Quarterly by the

International Standard Electric Corporation

67 BROAD STREET, NEW YORK, N.Y., U.S.A.

H. M. Pease, President S. G. Ordway, Secretary and Treasurer

Subscription, $3.00 per year; single copies, 75 cents

Volume XX 1941 Number 1

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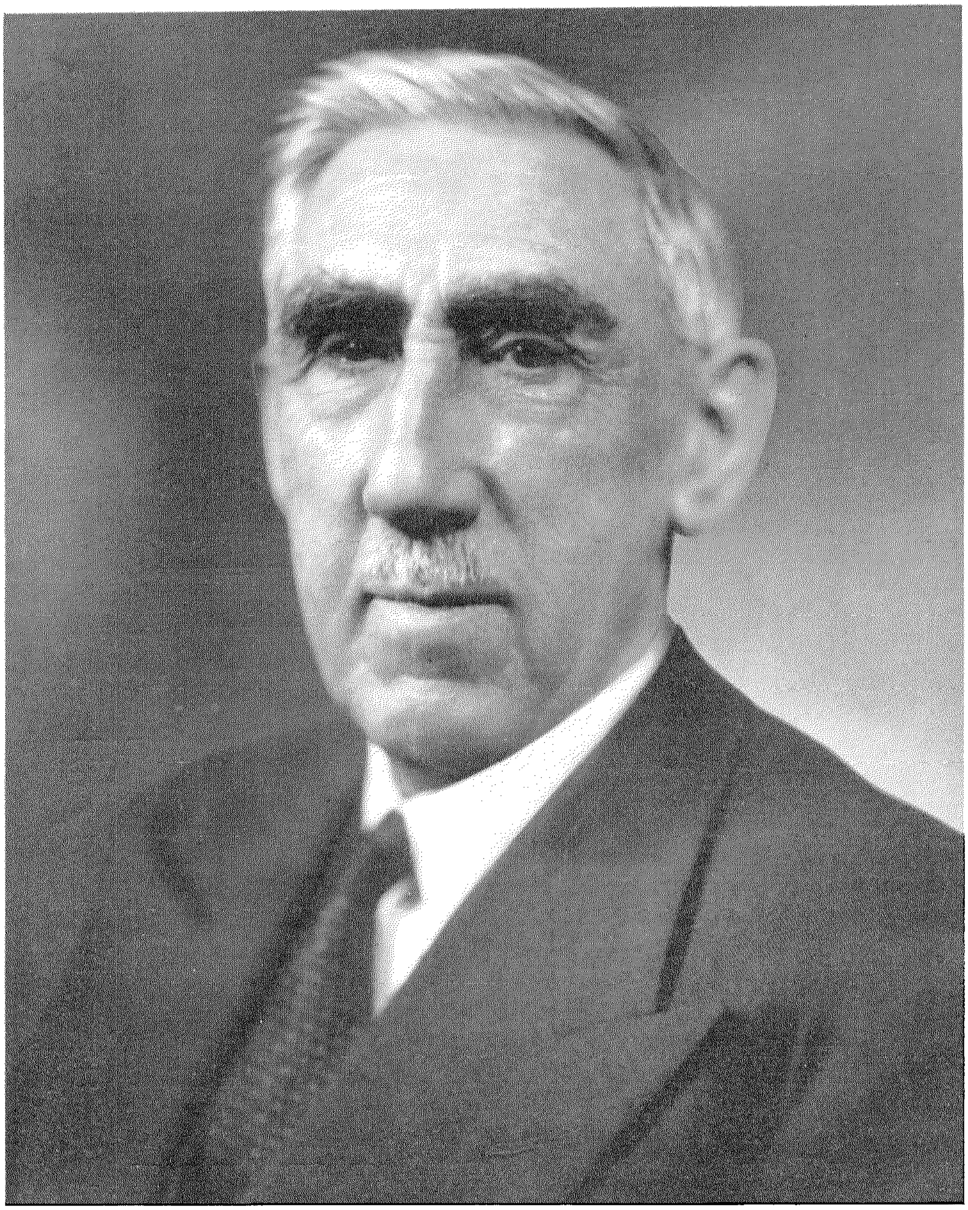

SIR FRANK GILL, K.C.M.G., O.B.E.

Sir Frank Gill, K.C.M.G., O.B.E.

By F. K. JEWSON

Assistant Vice President, International Standard Electric Corporation, London, England

THE English newspapers of June 12th, 1941, published the names of a number of people whose outstanding achievements have been rewarded by His Majesty the King, on the occasion of the celebration of his official birthday, by the award of various honours and distinctions. Amongst these was one of particular interest to all our readers; that of FRANK GILL, O.B.E., who was informed that His Majesty had been graciously pleased to give directions for his appointment to be a Knight Commander of the Most Distinguished Order of St. Michael and St. George for services in the development of the telephone industry and of international telephony.

Mr. Gill was born at Castletown in the Isle of Man and at the age of 16 entered the service of the United Telephone Company in London. After periods in Dublin, Liverpool and Blackburn, he returned to Dublin as District Manager, and in 1896 became the first Provincial Superintendent of the newly formed Province of Ireland of the National Telephone Company. Thus at the early age of 30 and fourteen years after starting his career he had reached a position which in the case of many telephone men proved to be their 'ultima thule' but not in the case of Mr. Gill.

In 1902 he was called to London to fill the position of Engineer-in-Chief of the National Telephone Company during a period which proved to be the most difficult of its existence. A change in the policy of the Government had allowed Municipalities to enter into competition with the National Telephone Company and it had been decided not to renew the franchise of the Company when it would expire at the end of 1911. The British Post Office (which had maintained a competitive system throughout the period of the franchise of the N. T. Co., confined mainly to official services and certain small exchanges in a few towns) had also entered directly into competition on a large scale in London. With the end of the franchise in sight, economy in capital expenditure was indicated but to meet the competition material improvements in the equipment were desirable. The Company, largely through the wisdom of its General Manager, W. E. L. Gaine, before his untimely death in 1907, found means of satisfying both requirements and made arrangements with the Government enabling a restricted progress in the telephone art in the British Isles to continue. During the last 7 years of the license most of the important exchanges in Great Britain were replaced by up-to-date common battery equipments and the telephone line wires continued to be put underground, whilst loading coils were introduced to bring circuits within desired transmission limits and transmission studies were made for all large towns. Indeed, planning went much further than this, for the efficiency of the service was such that without material changes conversations over lines much longer than could be found in these Islands would have been possible.

On January 1st, 1912, the Post Office took over the whole of the National Telephone Company's system except the 12 senior executive officers of the Company. In conjunction with Mr. W. W. Cook, Assistant Chief Engineer of the N. T. Co., the firm of Consulting Engineers, Gill & Cook, was formed and engaged in telephone work in various parts of the world including the U. S. A., Brazil, Argentine, Portugal and Turkey.

During the 1914–18 War Mr. Gill served in various capacities in the Ministry of Munitions, ending as Controller of the Central Stores Department. For these services he was made an Officer of the Order of the British Empire (O.B.E.).

In 1919 he accepted an offer of the post of European Chief Engineer of the International Western Electric Company and shortly after that there was commenced the introduction of long distance telephone cables in Europe. On the name of that Company being changed in 1925 to International Standard Electric Corporation he continued in the same capacity until 1928. During this period he was, in 1925/6, Vice President in Charge of Operations for the Spanish Telephone Company (Compania Telefonica Nacional de Espana) and began the reconstruction of the telephone system in Spain. He was also a member of the Postmaster

General's Committee which initiated Transatlantic Telephony.

The International Standard Electric Corporation elected him a Vice President of the Corporation. In 1929 while on a visit to Tokyo to attend the World Engineering Congress and the World Power Conference he was called to Shanghai, China, where he acquired for the I. T. T. System the business of the Shanghai Mutual Telephone Co. and undertook the reconstruction of the telephone system of the Shanghai Telephone Company, remaining until 1934. He is at present: a Director and a Vice President of International Standard Electric Corporation; Chairman of Standard Telephones and Cables Ltd., Creed & Company Ltd., and International Marine Radio Company, Ltd.

In 1922 he was elected President of the Institution of Electrical Engineers of which he had been a member since 1891 and selected as the subject of his inaugural address Electrical Communications with particular reference to international telephony. He drew attention to the achievements of the American Telephone & Telegraph Company in long distance telephony and pointed out that if distances alone were considered, telephone conversations could be carried on to all parts of the Continent of Europe and beyond with equal facilities. Long distance telephony had been possible in the U. S. A. because there had been one planning and coordinating authority, whereas there were some 40 in Europe, all with different ideas. Unless the circuit had been planned throughout with the same electrical characteristics, reflection and other losses occurred wherever there were variations. He proposed three alternative plans for dealing with this situation; one of which provided for an international telephone organisation with supervisory engineering powers. Early in 1923 the Department of Posts, Telegraphs & Telephones in France called an international meeting, of Government officials only, to consider these proposals and in 1924 the International Consultative Committee of Long Distance Telephony (C. C. I. F.) was formed, based on Mr. Gill's third proposal. To the efforts of this Committee we owe the success of long distance telephony in Europe, but the formation of the Committee is due to the vision of Mr. Gill.

After the war period it became apparent that something should be done to stimulate telephone development in a manner comparable with other European countries. At that time, the Postmaster General had no allocation of funds for advertising, and Mr. Gill in collaboration with others and with the consent of the Post Office authorities conceived the idea of the Telephone Development Association, of which he was President in 1935 and is serving in the same office again this year. He has also taken a great interest in the International Chamber of Commerce as a means for stimulating the demands of business men for better telephone facilities abroad.

Sir Frank Gill is a member of the Institution of Civil Engineers; Past President (1922) and Honorary Member (1938) of the Institution of Electrical Engineers; past Chairman of the China local branches of the Institutions of Civil and Electrical Engineers; Fellow of the American Institute of Electrical Engineers; Honorary Member of the Institute of Royal Engineers; Member of the Societe des Ingenieurs Civils de France and of the Societe Francaise des Electriciens; and Past President of the Association of Supervising Electrical Engineers.

Since the announcement of the honour conferred on him by the King, Sir Frank has been feted by most of the associations with which he has been associated, including, on June 16th, his entertainment by the Postmaster General, supported by the Assistant P. M. G., the executive officers past and present of the Post Office and representatives of the Telephone Industry.

That his arduous work and wonderful achievement in the development of the telephone industry and of international telephony has at last been publicly acknowledged is gratifying to the numerous friends throughout the world whom he has made during his long career; particularly as he has always been so modest and content to do whatever came to hand with enthusiasm and singleness of purpose, considering that the achievement of a duty well done was sufficient reward.

We offer our hearty congratulations to Sir Frank and Lady Gill and wish them many years to enjoy the honour which they so richly deserve.

Airport Communications

By R. H. RIDDLE

International Standard Electric Corporation, New York, N. Y.

Introduction

THIS article outlines the principal communication requirements of an airport, traces developments meeting these requirements, and describes some of the most modern equipment now in use or soon to be adopted, with particular reference to the facilities at La Guardia Field, the Municipal Airport of the City of New York, including those provided by governmental agencies and the commercial airlines.

The communications facilities required at an airport fall naturally into four functional groups, namely:

(*a*) Internal communication;
(*b*) Communication with outside fixed points and with other airports;
(*c*) Communication with aircraft;
(*d*) Auxiliary services such as radio direction finding on land, instrument landing and radio beacons.

The first part of the article is consequently devoted to a general discussion of groups (*a*), (*b*), and (*c*), in which European and American practices are indicated, with comment on the respective specialized applications, relative advantages, safety aspects and economic considerations. This is followed by consideration of the requirements and the equipment used at La Guardia Field, and (*d*) by brief descriptions of the latest developments in instrument landing and radio direction finding on land.

Internal Communications

In a modern airport, a flexible and efficient communication system interconnecting various internal departments is obviously indispensable. Centralization and coordination of functions, speeding up of procedure and avoidance of excessive auxiliary personnel depend to an important degree on the adequacy of the communication facilities.

The internal telephone system, preferably utilizing a private automatic branch exchange (PABX) [1] should be of adequate capacity for immediate needs and for reasonable future expansion. It must be capable of rendering reliable and speedy service to all units comprised in the airport, i.e., from the control tower to a series of strategic points bordering the field, as well as interconnection of shops, hangars, offices of the official staff, offices of private aviation companies located at the airport, etc.

Where permanent and instantaneous intercommunications are required, such as between two or more functionally allied departments or offices, so-called interphones are indicated. The use of interphone systems, however, should be restricted to special cases since the particular advantages of such systems—especially personal and immediate contact—decrease with expansion of the number of telephones involved. Beyond a certain stage, an internal telephone system is essential. Experience indicates that interphone systems should be used to supplement, but never to supplant an internal telephone system.

For the transmission of general orders, announcements to passengers or the public, paging individuals, control on the runways, emergency reports, etc., a loudspeaker public address system is required. The system should be arranged for transmission of orders and reports from various control points of the airport, including the possibility of instant selection of groups of loudspeakers covering the departments concerned. Microphone circuits at the various control points should be arranged for automatic priority throughout the system in order to prevent operation of two or more microphones simultaneously.

Weather reports, messages or orders concerning aircraft traffic, passenger lists and similar communications, which it is desirable to file for record purposes, may be transmitted between neighboring departments by means of pneumatic tubes.

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[1] For numbered references, see end of article.

For greater distances, teleprinters are more economical. They offer an appreciable advantage, not only because of instantaneous transmission, but also because of the practicability of simultaneous reception at various points in and outside the airport. In addition, their ability to print several copies facilitates distribution from key points, either by hand or through pneumatic tubes.

Teleprinters of the usual type are suitable for this purpose. In certain cases roll or tape rather than page printing machines are to be preferred, according to the requirements of individual departments.

Teleprinter messages can also be transmitted by means of a perforated tape such as is used in automatic telegraph offices. The operator prepares the tapes on a perforator and places them in the transmitting machine as circuits become free. Transmission is effected automatically, the operator being left free to prepare other messages on tapes, or to supervise other circuits. Piling up of messages is thus avoided at points where the traffic load is irregular; furthermore, tape perforations are useful for the automatic re-transmission of messages to side routes.

Selection of lines in the case of teleprinters is effected through a switchboard, similar to a small telephone exchange but embodying certain special features. Manual switchboards are used as a rule inasmuch as the teleprinter operators can readily supervise them and line changes are infrequent.

For communication between the control tower and mobile equipment of the airport, such as fire engines, accessory equipment for instrument landing, snow plows, successful use has been made at times of small portable radiotelephone equipments of very low power, operating on ultra-high frequency bands between 100 and 300 megacycles (1 to 3 meters).

Communication with Outside Fixed Points and with Other Airports

Telephone service to outside fixed points is usually handled through a manual private branch exchange (PBX) of one or more positions with trunks to the public telephone exchange.

Such a PBX provides telephone connections to all rooms and other places patronized by passengers and the public in general, and also to non-official agencies of the airport. In addition, it provides official and allied airport agencies with connections to the public telephone exchange. Calls from official airport agencies should originate through the PABX referred to above.

For emergency calls, the PBX should have available a microphone with control over the public address system previously mentioned.

In addition to telephone service to points outside the airport, provision must be made for the installation of a public telegraph office, including subsidiary offices for public and official airport use.

Communications with the official meteorological services obviously are especially important. For the transmission of weather reports to airports, teleprinter circuits have been adopted practically universally. They enable the weather bureau to transmit, simultaneously and in a single operation, messages to the main airport, other airdromes and its own agencies. Thus, messages may be received in record form with copies, as required, for internal distribution. Important, also, is the provision of an independent standby circuit interconnecting the weather bureau of the airport with the flight direction office of the airport.

Other direct circuits—telephone, telegraph or teleprinter—may be required to link the operations offices of governmental controlling agencies and to connect the airport offices of the airlines with local and distant ticket, sales and reservation points.

In areas of heavy aircraft traffic, direct communication with nearby airdromes is of great importance and may become essential. Physical or ultra-high frequency radiotelephone circuits are preferable since they avoid congestion of radio communication bands employed for normal services.

Communication with other airports and airdromes on the main flying routes under certain conditions may be provided advantageously by physical circuits. Due partly to the existing congestion throughout nearly the whole radio communication frequency spectrum, radio circuits are not, as a general rule, provided between airports in the U. S. A.

In Europe, up to the end of 1939, a definite tendency was noted towards the suppression of radio communication for these services, physical teleprinter circuits being used, the same as in the U. S. A.

In the U. S. A., however, the cost of long distance teleprinter circuits is still substantially more than that of an equivalent radio circuit. On comparatively short circuits carrying heavy traffic the use of the teleprinter circuit is economically justified, but on longer circuits where traffic is light the economic factor compels use of radio circuits. In countries presenting broad expanses of territory combined with relatively undeveloped communications networks the economic considerations in favor of radio circuits are even greater, and in some cases radio may be the only possible means of communication.

Installations providing such radio channels may be made by the companies themselves, or the necessary equipment and personnel may be furnished by governmental authority. The equipment, in either case, must meet the requirements of all commercial lines using the airport; that is, for their communication with airports serving as landing points, auxiliary emergency airports, official weather bureaus, weather bureaus maintained by the aviation companies, etc.

For airport inter-communications in the aeronautical service bands, account must be taken of the definition approved at the Second Inter-American Radio Communications Conference in Santiago, Chile (1940). That definition, which agrees with the findings of previous world and regional conferences, establishes that aeronautical service consists exclusively in the transmission and reception of information contributing to the safety of aircraft in flight. Messages of an administrative and private nature would not, therefore, be included in this category; these may be classified as "point-to-point service" to be transmitted in the bands assigned to this latter service.

Communications with Aircraft in Flight

Communications with aircraft in flight generally are accomplished by radiotelephone and radiotelegraph.

The airport must be equipped to maintain communication with aircraft within the perimeter of its particular zone. If individual equipments are not installed by the commercial air lines, alternative arrangements must be made for governmental or other agencies to render this service and to keep in contact with aircraft at least until the zone of the next airport is reached.

This latter practice was common in Europe, up to the end of 1939, where the more important air services were primarily international; that is, in most cases the plane left an airport in one country to fly directly to an airport in another country. Jurisdictional problems consequently arose, requiring solution by international agreement.

In the U. S. A. the problem is largely a national one and has been solved as such. All flight activity throughout the country is subject to instructions from Airways Traffic Control of the Federal Civil Aeronautics Administration.

Planes on the field or in the immediate vicinity of the airport communicate directly with the airport control tower. Outside these "local control tower areas" all communication with commercial planes is through the facilities of the airline concerned.

For communication with military and itinerant planes outside the tower zone, facilities are provided by the Civil Aeronautics Administration. For navigation between airports, all planes may use the radio beacons and markers which are also provided and operated by the Civil Aeronautics Administration.

Both systems, experience shows, involve certain disadvantages. European methods, covering practically integral control, are simpler but not easily adaptable to very heavy air traffic conditions. American practice, involving a multiplicity of radio circuits with strict control and perfect coordination, is better adapted to the needs of terminal airports or points of converging air traffic.

The number of radio installations required at an airport is dependent on actual traffic volume and the probabilities of near and longer term traffic growth.

The principal transmissions from an airport to an airplane include weather reports of a general or specific character, flight instructions, emergency calls or danger warnings, bearings for direction finding and instructions for take off and landing. From aircraft, the transmissions primarily concern bearings, changes in flying alti-

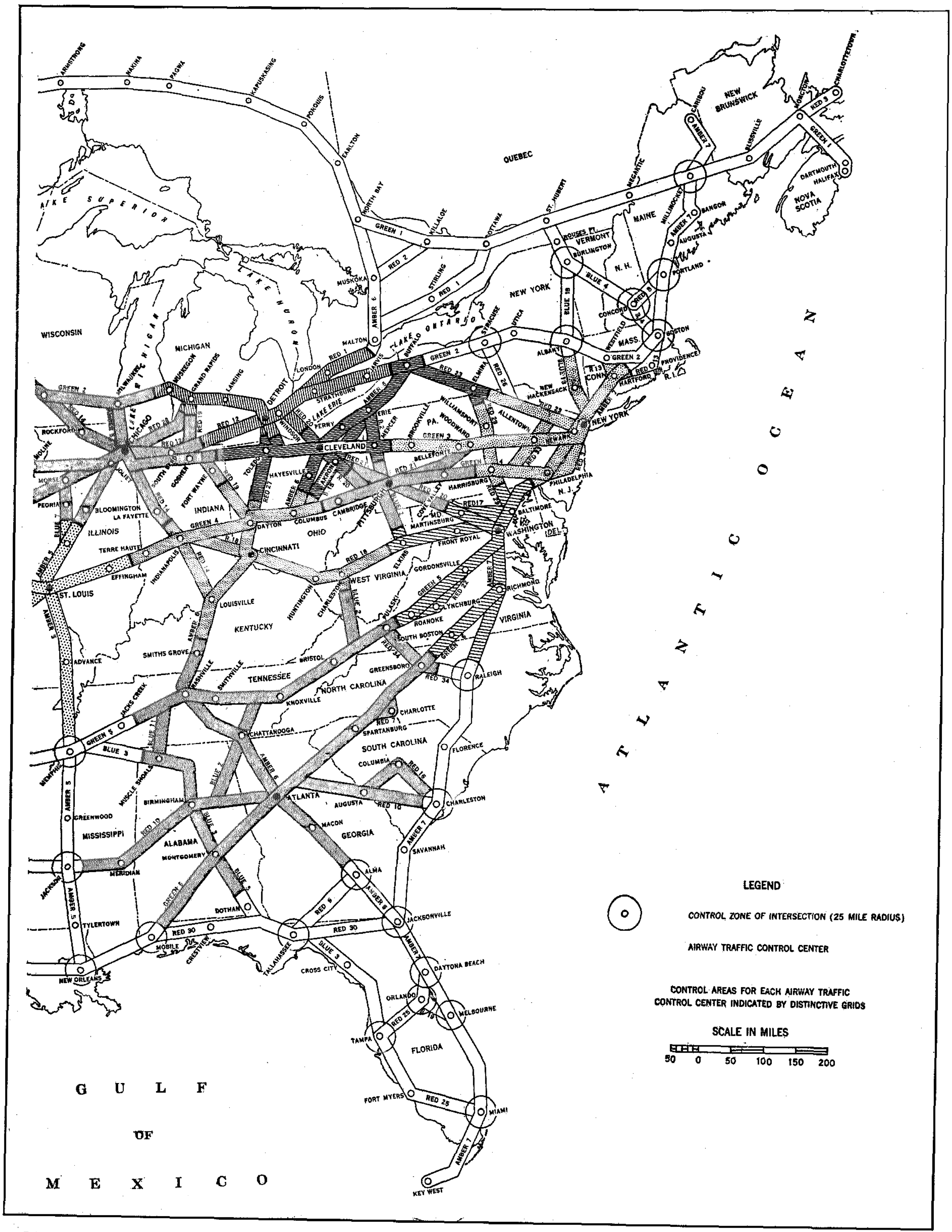
LEGEND
CONTROL ZONE OF INTERSECTION (25 MILE RADIUS)
AIRWAY TRAFFIC CONTROL CENTER
CONTROL AREAS FOR EACH AIRWAY TRAFFIC CONTROL CENTER INDICATED BY DISTINCTIVE GRIDS
SCALE IN MILES
50 0 50 100 150 200
ATLANTIC OCEAN
GULF OF MEXICO
QUEBEC
NEW BRUNSWICK
NOVA SCOTIA
MAINE
VERMONT
N. H.
NEW YORK
MASS.
CONN.
R. I.
PA.
N. J.
DEL.
MD.
VIRGINIA
WEST VIRGINIA
OHIO
MICHIGAN
WISCONSIN
INDIANA
ILLINOIS
KENTUCKY
TENNESSEE
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
ALABAMA
MISSISSIPPI
FLORIDA
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
CHICAGO
DETROIT
CLEVELAND
PITTSBURGH
BUFFALO
NEW YORK
BOSTON
PHILADELPHIA
WASHINGTON
BALTIMORE
RICHMOND
CINCINNATI
COLUMBUS
DAYTON
INDIANAPOLIS
ST. LOUIS
LOUISVILLE
NASHVILLE
MEMPHIS
CHATTANOOGA
ATLANTA
BIRMINGHAM
MONTGOMERY
JACKSON
NEW ORLEANS
MOBILE
TALLAHASSEE
JACKSONVILLE
SAVANNAH
CHARLESTON
CHARLOTTE
GREENSBORO
RALEIGH
ROANOKE
LYNCHBURG
DAYTONA BEACH
ORLANDO
TAMPA
MELBOURNE
FORT MYERS
MIAMI
KEY WEST
MALTON
LONDON
WINDSOR
NORTH BAY
OTTAWA
ST. HUBERT
MONCTON
HALIFAX
DARTMOUTH
CHARLOTTETOWN
BANGOR
PORTLAND
CONCORD
ALBANY
SYRACUSE
UTICA
ELMIRA
HARTFORD
PROVIDENCE
NEWARK
HARRISBURG
ALLENTOWN
WILLIAMSPORT
BELLEFONTE
GREEN 1
GREEN 2
GREEN 3
GREEN 4
GREEN 5
GREEN 6
RED 1
RED 2
RED 9
RED 18
RED 25
RED 34
RED 90
AMBER 5
AMBER 6
AMBER 7
BLUE 3
BLUE 4
BLUE 7

Fig. 1—Airway Traffic Control Areas of the United States and Canada. (Territory east of St. Louis, Missouri.) Reproduced from portion of map issued by Civil Aeronautics Administration, Department of Commerce, Washington, effective June 1, 1941.

tude, flying conditions, emergency calls, requests for landing authorization, etc.

At an important airport, where air traffic is or may become very heavy, separation of the receiving station from the transmitting station is in general desirable.

In Europe and elsewhere (partly due to lack of agreement on frequency standards), receivers frequently are located at or near the control tower of the airport. Since they are tuned by hand, contact can readily be maintained on medium or short waves with aircraft having equipment of the master oscillator type variable within the mobile or aeronautical service bands, and in many cases interference is avoided. Transmitters are placed at convenient distances, generally with manual control for starting, change in frequency and service, and are attended by personnel receiving orders by telephone. This arrangement has its advantages, especially in medium and long wave working, since the size of the transmitting antennas may present an appreciable flying hazard if placed near the landing runways.

In some instances, it has also been necessary to remove the radio direction finding installations from the airport. Modern Adcock radio direction finders, however, permit installation of their aerial system at a certain distance from the receiver so that this drawback has been reduced.

In the United States, control is unilateral and fixed frequencies have been assigned to all the services. It has thus been possible to provide automatic installations operated by remote control on pre-assigned frequencies, both for transmitting and receiving equipments.

LA GUARDIA FIELD (City of New York)

The preceding discussion deals with airport communications requirements in comparatively general terms. The following, (involving (1) the Civil Aeronautics Administration, (2) commercial airlines and (3) airport controls) is intended to present more specific and detailed information; it is confined to the systems and methods now used in the U. S. A., or, more particularly, to equipment now in operation or soon to be installed at La Guardia Field, Municipal Airport of the City of New York.

As a municipally owned airport, La Guardia Field is under the Department of Docks of the City of New York. All communications facilities serving the airport as a whole, such as the control tower and the public address system, are therefore provided and operated by the Department of Docks.

Airlines using La Guardia Field include United Airlines, Eastern Airlines, American Airlines, Transcontinental and Western Air, Inc. and Canadian Colonial Airways, Inc. Pan American Airways operates from the Seaplane Base, also a part of the Municipal Airport; its facilities are not described in this article.

Civil Aeronautics Administration

GENERAL

For purposes of coordination and enhancement of safety, the Civil Aeronautics Administration delegated responsibility to Airways Traffic Control for dispatching and controlling all flying activity—commercial, military and itinerant—throughout the U. S. A. Through its Communications Division, the Civil Aeronautics Administration, in addition, undertook the gathering and distribution of information on weather conditions, flight control and progress reports involving the entire country. The Civil Aeronautics Administration also is responsible for the operation of radio beacons and markers.

AIRWAYS TRAFFIC CONTROL—NEW YORK AREA

The Airways Traffic Control office at La Guardia Field supervises flight operations within the New York Control area, which comprises the territory indicated in the map of Fig. 1. This area includes the airports of Newark (New Jersey), Philadelphia, Harrisburg (Pennsylvania), Middletown (New York), and the nearby Floyd Bennett, Mitchell and Roosevelt Fields (Long Island, N. Y.), all of which receive their flight instructions from Airways Traffic Control at La Guardia Field.

Instructions to commercial airplanes, while in flight *between airport control tower areas*, are relayed through the ground-airplane-radio facilities of the airline concerned. Contact with military and itinerant planes, however, is made directly from Airways Traffic Control by radio (as described below) until the plane comes *within the airport control tower area.*

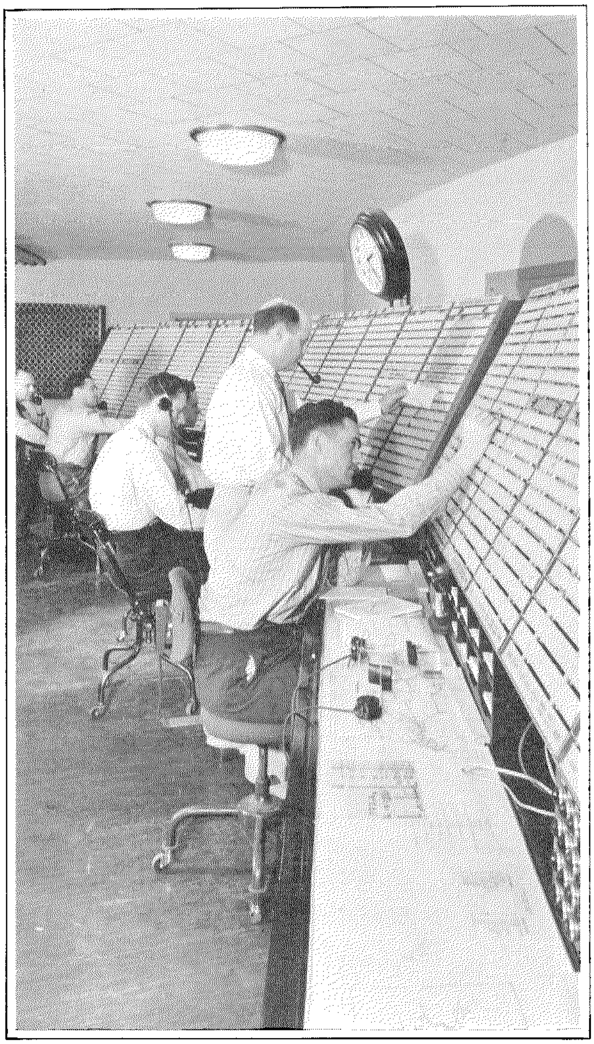

Fig. 2—Operations Board—Airways Traffic Control.

Airways Traffic Control Equipment

For communication with other airports in the New York Control Area and for transmission of flight instructions to the communications centers of the airlines at La Guardia Field, telephone lines are used exclusively by Airways Traffic Control. In the case of the other airports, the lines are operated on a conference basis. Operators monitor the line at all points and come into answer when called. The local lines to the communication points of the airlines are operated on the usual ring-answer basis. A view of the operations board is shown in Fig. 2.

For communication with military and itinerant planes, Airways Traffic Control has its own radio receivers, installed near the operations board, and transmits over the Airport "range and simultaneous broadcast" transmitter. This transmitter, supplied by the Federal Telegraph Co., operates on a fixed frequency of 209 kc. It is modulated continuously with tone at a level which permits speech to be imposed on it with adequate intelligibility. One receiver monitors 3,105 kc for reception from itinerant planes; another monitors 4,495 kc from military planes. In addition, the tone signal of the range transmitter is monitored (on 209 kc) and the local control tower on 362 kc.

Weather Reports

Adequate weather information must be received at the airport to enable the airlines and Airways Traffic Control to plan and control flights. As indicated above, the Communications Division of the Civil Aeronautics Administration is responsible for this service. The information is supplied by weather stations of the Weather Bureau of the U. S. Department of Commerce, except at points where there are no such weather stations, in which case employees of the Civil Aeronautics Administration are trained and authorized to make observations. Reports come to the Communications Office at La Guardia Field over several circuits and are relayed to its Airways Traffic Control as well as to the flight planning offices of all airlines at the field, to all other services in the locality subscribing to the service and to all connecting distribution circuits. Such reports, of course, include those supplied by the weather station and Airways Traffic Control at La Guardia Field.

Equipment for Weather Reports

The weather reporting service at La Guardia Field employs thirteen sets of teletype equipment, each set consisting of a printer with its associated reperforator and a transmitter. The reperforators associated with the printers are used when required to perforate a tape simultaneously with reception of the information in printed form on the printer. This tape may then be transferred to the transmitter for transmission of the reports to other distribution points and to local subscribers. One similar set of equipment is used for the flight control and progress report circuit. The typewritten copies received on the printers are sent to Airways Traffic Control through a pneumatic tube system.

Airline Requirements

Each airline must have facilities for communicating with its planes in flight, for transmitting and receiving operating information to and from other airports on its routes, for relaying flight information from its planes to Airways Traffic Control, for relaying messages to and from the local reservations office and its reservations offices in other cities, and for intercommunication between its various offices at the airport.

As an example of the requirements and equipment used by a major airline in the U. S. A., the facilities of American Airlines at La Guardia field are described in the following paragraphs. American Airlines, in general, was selected for this purpose in view of the fact that its general offices are located at La Guardia Field, which also is the terminus of the three distinctly separate routes flown by the line, with 122 flights in and out of New York daily, exclusive of extra sections. The extent of the operations carried on by American Airlines at La Guardia Field, moreover, demands what are perhaps the most elaborate facilities of any one airline at one airport, and it is thought that this very fact makes the installation of outstanding interest since the outlines of simpler systems are easily recognizable in such a relatively complex one. This fact should be kept constantly in mind, however, since correspondingly less equipment is, of course, required at the terminal airport of a single route or at an intermediate airport.

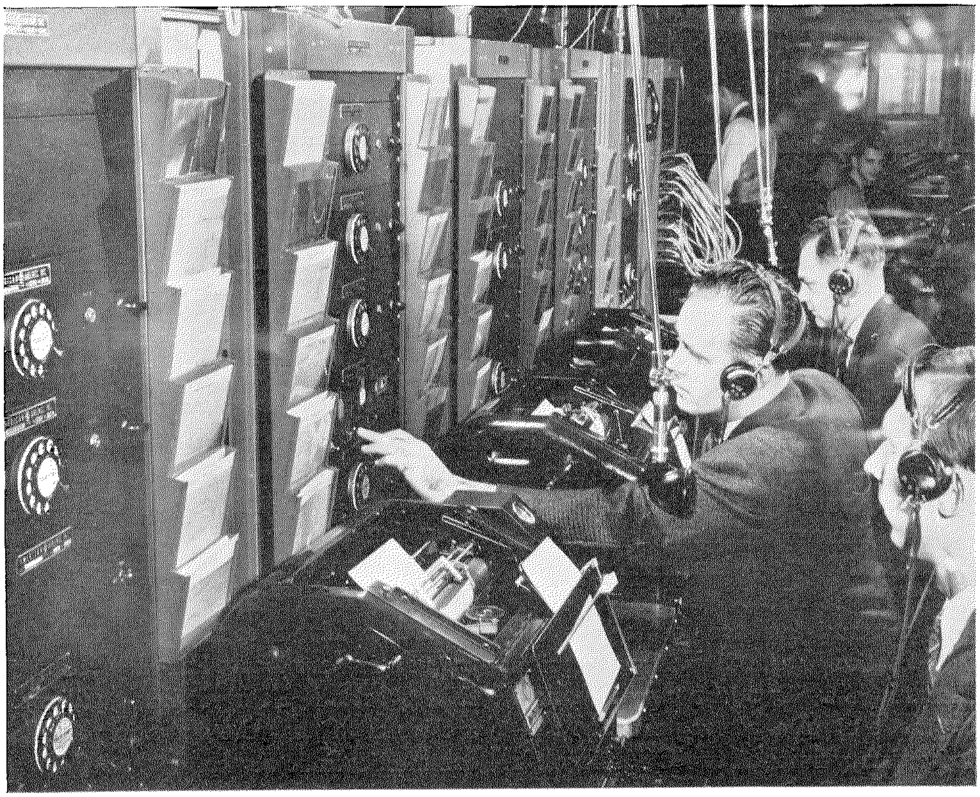

Fig. 3—Radiotelephone Operating Positions, Communications Center of American Airlines, La Guardia Field, North Beach Airport, New York.

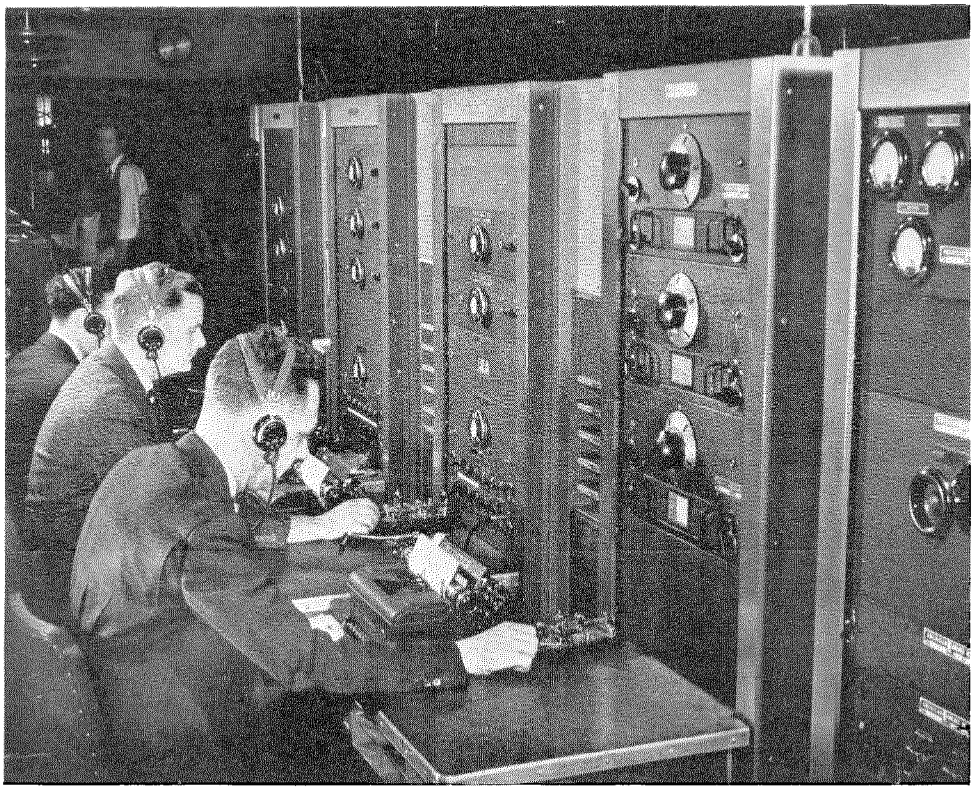

Fig. 4—Radiotelegraph Operating Positions, Communications Center of American Airlines, La Guardia Field, North Beach Airport, New York.

American Airlines Facilities

Figs. 3 and 4 show, respectively, the radiotelephone and radiotelegraph operating positions in the communications center of American Airlines, from which telephone communication is maintained with planes in flight and telegraph traffic is handled with communications centers at some of the other airports. A block schematic of the system is shown in Fig. 5.

Four radio transmitters are located at the Jamaica Bay Station, approximately ten miles south of the airport. Two are multi-channel transmitters made up of a power unit, one telephone radio frequency unit and two CW telegraph units. Each of the radio frequency units is rated at 3 kw antenna output and is arranged for selection of six operating frequencies by remote control. The third transmitter is a single channel CW or telephone unit with an output rating of 1 kw, and is arranged for remote selection of ten frequencies. The fourth is a 250 watt unit for remote selection of six frequencies on CW telegraph only.

In addition, three auxiliary transmitters for telephone use only, rated at 50 watts and operating only on two frequencies, are installed near the operating positions in the communications center.

Seven receivers, each crystal controlled for two frequencies, are located at the station on nearby Rikers Island. Four similar auxiliary receivers are installed near the operating positions in the communications center.

As shown in the schematic (Fig. 5), all of the above transmitters and receivers are wired into a jack field at which circuits from the operating positions also terminate. Operating circuits are patched through as required; the remotely installed radio equipment is under the complete control of the operators through the remote control units at each operating position.

As mentioned above, the radiotelegraph facilities are used for communication with certain other airports on the routes of the American Airlines. In general, radiotelegraph circuits are used only to distant points, not involving heavy traffic. For the shorter distances and heavy traffic points, leased wire teletype circuits are used, supplemented by Telemeter and Teletype Exchange facilities.

The teletype operating section of the communications center is pictured in Fig. 6. The machines shown include the transmitter and the typing reperforator on the circuit to the reservations office in New York and the machine in the circuit linking the ticket offices, sales office, reservation office in New York and the general offices at the airport. Block schematics of the circuits in which these machines operate are given in Figs. 7 and 8.

Reperforators associated with each of the nineteen machines in the communications center at La Guardia Field (Fig. 8) are used to punch tapes for all messages from other points to the reservations office in New York. Messages from the New York reservations office are received on the typing reperforator, and the tapes are run on the circuit corresponding to the appropriate reservations office.

Teletype circuits also are used to relay flight information from airplanes to Airways Traffic Control. These machines are located at the three radiotelephone positions shown in Fig. 3, corresponding to the three routes flown by the Company. While the operator is receiving messages from the plane, he types them directly on the Teletype so that the message appears simultaneously in his machine and in the printer near the

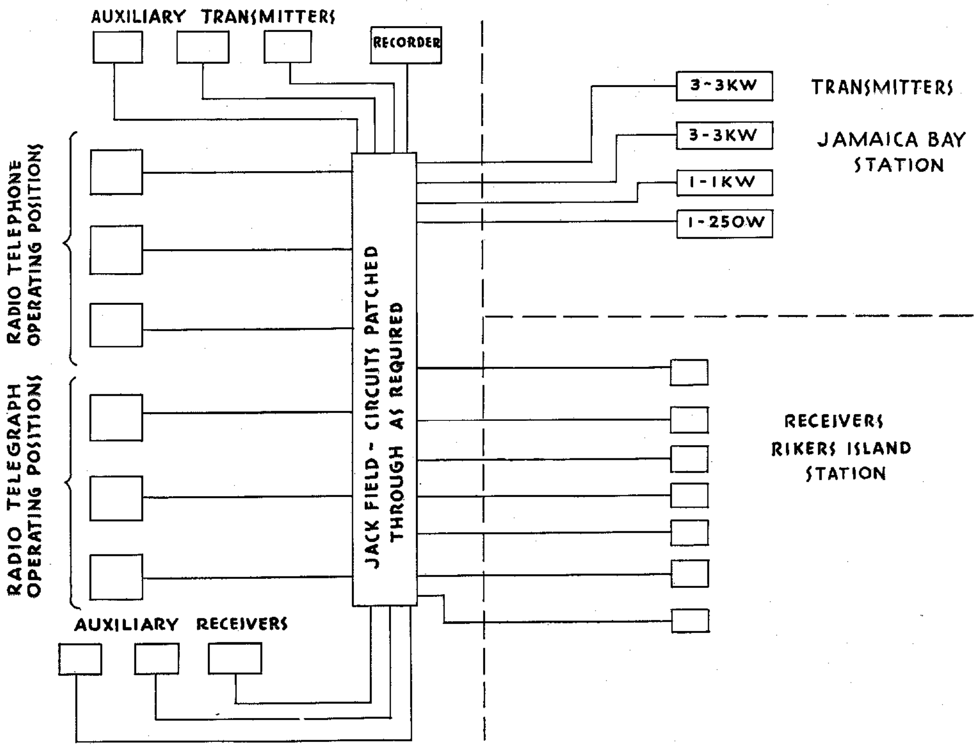
AUXILIARY TRANSMITTERS
RECORDER
3-3KW
3-3KW
1-1KW
1-250W
TRANSMITTERS
JAMAICA BAY STATION
RADIO TELEPHONE OPERATING POSITIONS
RADIO TELEGRAPH OPERATING POSITIONS
JACK FIELD - CIRCUITS PATCHED THROUGH AS REQUIRED
RECEIVERS
RIKERS ISLAND STATION
AUXILIARY RECEIVERS

Fig. 5—Schematic of Radio Transmitting and Receiving Facilities, American Airlines, La Guardia Field, New York.

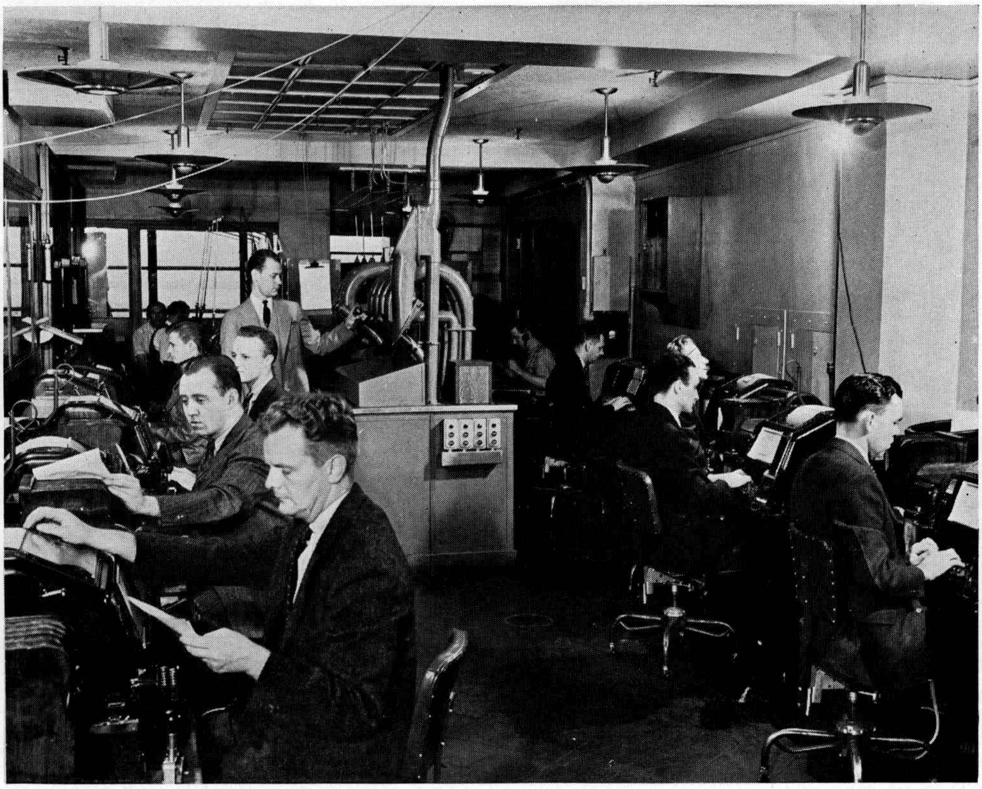

Fig. 6—Teletype Operating Positions, Communications Center of American Airlines, La Guardia Field, North Beach Airport, New York.

operations board in Airways Traffic Control. The copy typed by the operator immediately is handed by him to the adjacent flight planning office of the airline.

In this flight planning office, weather reports also are received from Civil Aeronautics Administration lines. An hour before the scheduled departure of an airplane, the chief pilot, in collaboration with the flight planning supervisor, considers the flying conditions likely to be encountered and plans his flight, use being made of the latest information available through radio and teletype facilities.

Flight instructions are received in the flight planning office from Airways Traffic Control over a private telephone line.

For internal communication at the airport, American Airlines employs a standard 300 line PAX. This is supplemented by a seven-position PBX with trunks to local central office exchanges.

A loudspeaker intercommunication system links the general offices, communication center, ticket center, agents, airmail and baggage offices. It is arranged for station-to-station operation or for broadcasting to all stations.

Multi-Channel Transmitter of United Airlines

Multi-channel radio transmitters for airline operation recently installed by the United Airlines at La Guardia Field represent the most modern developments and refinements in this type of equipment.[2] They were engineered and manufactured by the Federal Telegraph Co. and are used by United Airlines for telephone contact with planes in flight and for point-to-point telegraph traffic.

Electrically and mechanically, this equipment is subdivided into four basic units similar in size and outward appearance, i.e., the power supply unit, modulator unit, radio frequency unit and central cooling unit (Fig. 9).

The power supply unit will operate radio frequency units individually or a limited number simultaneously. The modulator unit is capable of completely modulating a single radio frequency unit. Each radio frequency unit is a complete assembly capable of operation on a single frequency independently of all other radio frequency units. Control and switching are accomplished in primary power circuits, thereby eliminating troublesome RF switching.

The power supply unit together with a radio frequency unit constitutes the minimum equipment for single frequency telegraph service. The addition of a modulator unit provides single frequency telephone service. Individual modulator units may be associated with more than one radio frequency unit for telephone service on more than one frequency, but only one radio frequency unit may then be modulated at one time.

Provision is made for remote control of the following functions: (*a*) application of filament primary voltage; (*b*) removal of filament primary voltage; (*c*) application of plate voltage; (*d*) removal of plate voltage; (*e*) selection of any RF unit for operation; (*f*) keying of individual RF units for telegraph service; and (*g*) push-to-talk microphone switching for telephone service.

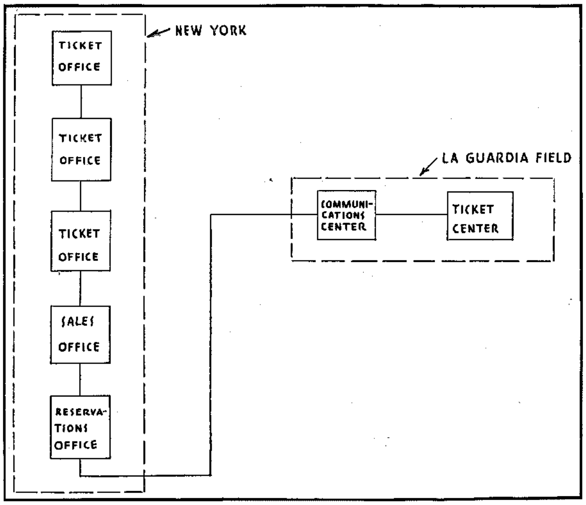
NEW YORK
TICKET OFFICE
TICKET OFFICE
TICKET OFFICE
SALES OFFICE
RESERVATIONS OFFICE
LA GUARDIA FIELD
COMMUNICATIONS CENTER
TICKET CENTER

Fig. 7—Local Teletype Circuit, American Airlines, New York.

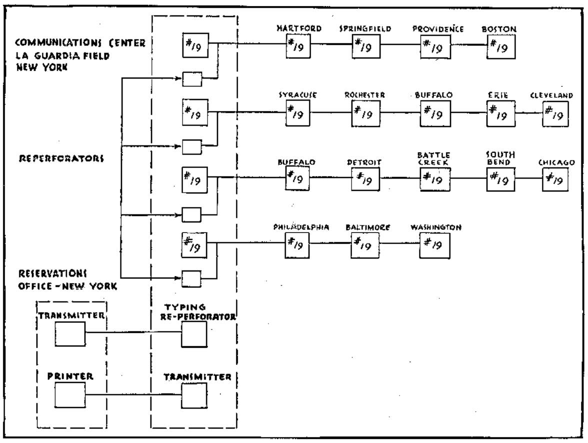
COMMUNICATIONS CENTER LA GUARDIA FIELD NEW YORK
REPERFORATORS
RESERVATIONS OFFICE - NEW YORK
TRANSMITTER
PRINTER
TYPING RE-PERFORATOR
TRANSMITTER
#19
HARTFORD
SPRINGFIELD
PROVIDENCE
BOSTON
SYRACUSE
ROCHESTER
BUFFALO
ERIE
CLEVELAND
BUFFALO
DETROIT
BATTLE CREEK
SOUTH BEND
CHICAGO
PHILADELPHIA
BALTIMORE
WASHINGTON

Fig. 8—Long Lines Teletype Circuits, American Airlines.

These remote control circuits are actuated by completing the respective relay circuits through a remotely controlled switching mechanism such as a telephone type of stepping switch. The same circuits may be switched manually by extending the circuits to a local control switching panel.

Control Tower Requirements (City of N. Y. —Municipal Airport)

As planes approach within 10 minutes flying distance, or approximately twenty-five to thirty miles of the airport, control of their flight is shifted from the airline or Airways Traffic Control, as the case may be, to the airport control tower. The control tower receives from commercial planes on the frequencies used for contacts with their respective communications centers. Commercial planes, however, call the tower on their night frequency during the day, and on their day frequency at night, in order to avoid interference with other planes of the line talking to their own communication center. Since military, police and itinerant planes also must receive their landing instructions from the tower, the transmitting frequencies of such planes must be available to the control tower. In addition,

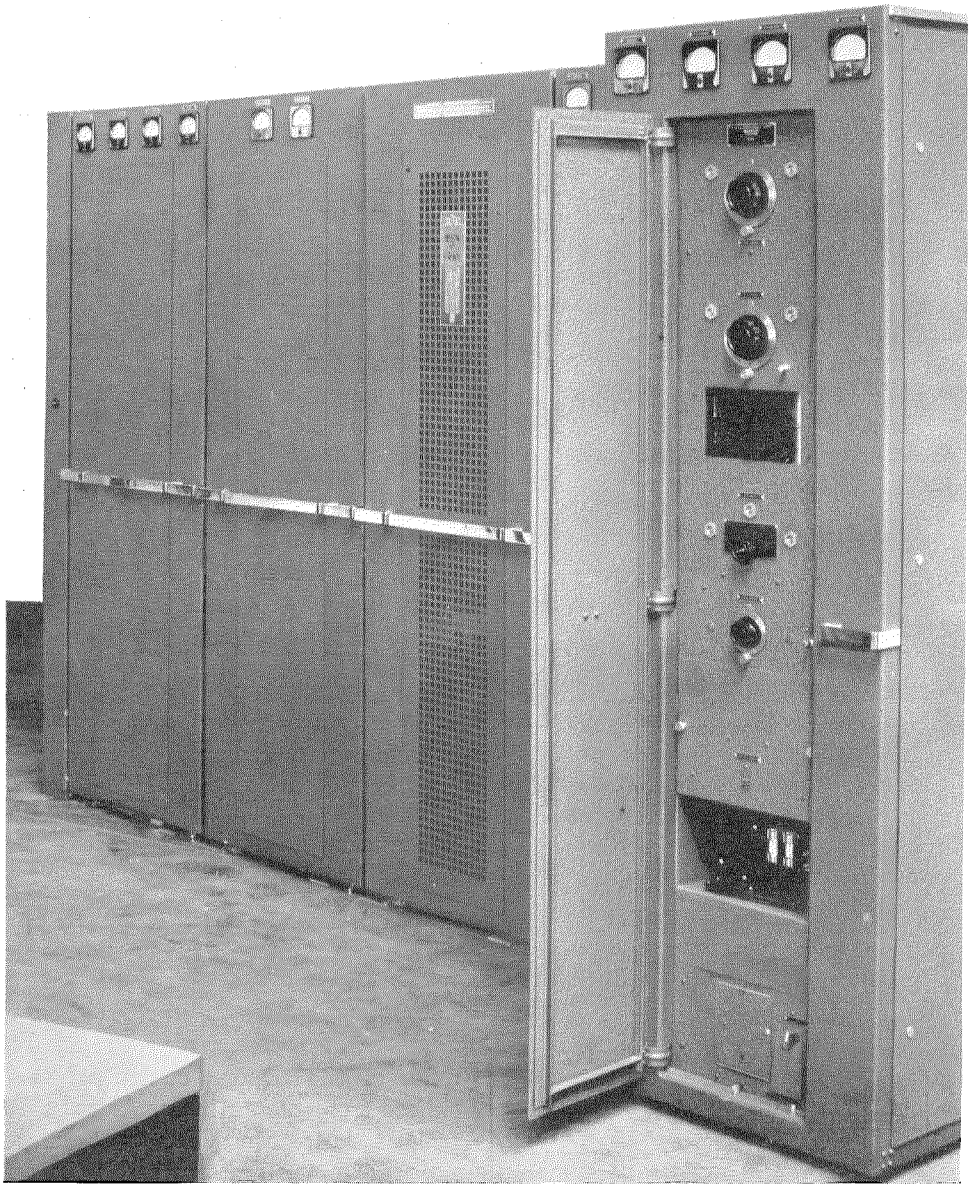

Fig. 9—Five Kilowatt Unit Type Multi-Channel Federal Telegraph Company Transmitter.

facilities for communication with the Airways Traffic Control officer are required, as well as a system for instantaneous contact with the communications centers of all the airlines. Another essential item in the control tower is a microphone of the airport public address system.

Control Tower Equipment

Fig. 10 shows the interior of the control tower at La Guardia Field. In the center of the control console are the various wind direction and velocity indicating instruments, and airport lighting

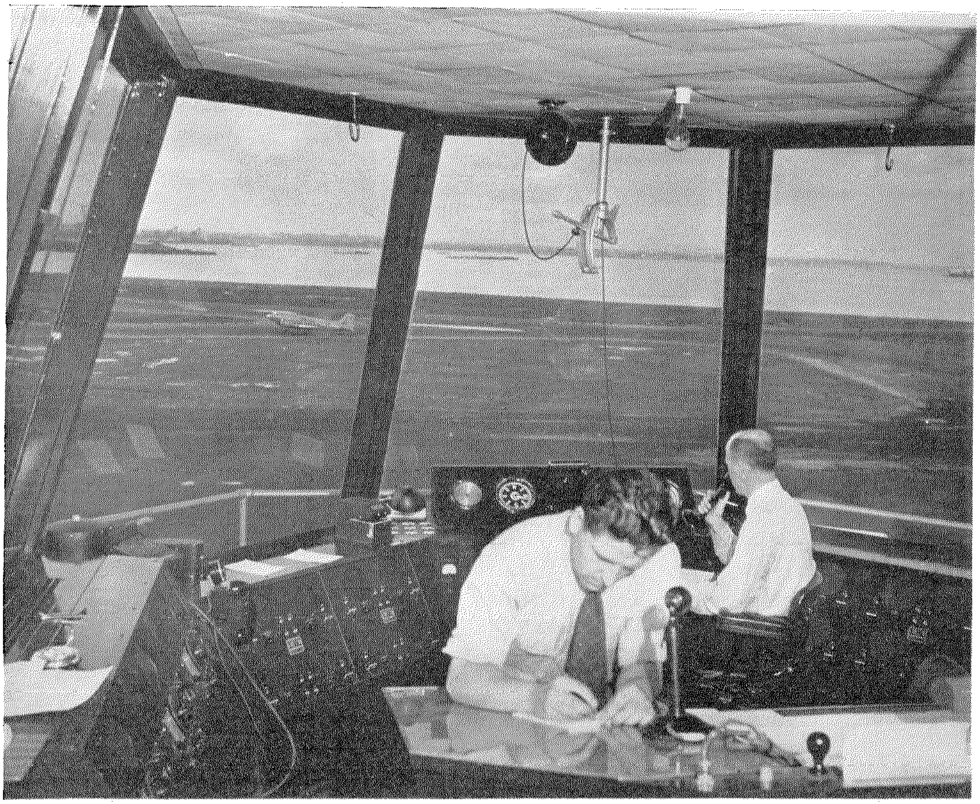

Fig. 10—Interior of Control Tower, La Guardia Field.

controls. On the left and right of the center panel are loudspeaker units from the remote receivers. At the extreme position on both wings of the console are the local auxiliary (emergency) receivers; directly below but not visible in the picture are transmitters and receiver line amplifiers.

Two transmitters operate at fixed frequency with 15 watts antenna output. The standard control tower transmitting frequency for the U. S. A. is 278 kc; La Guardia Field, however, is an exception in that it operates on 362 kc to avoid interference with the nearby Floyd Bennett Field. Ultra-high frequency for control tower operation is a recent innovation; a transmitter operating on approximately 130 mc is now in use at La Guardia Field simultaneously with a 362 kc transmitter. Both transmitters are modulated by the operator's dynamic microphone through a line amplifier. While at present very few planes are equipped to receive and transmit on the ultra-high frequencies, it is expected that all control tower communication eventually will be shifted to this range.

A group of fifteen 23-A Western Electric receivers are installed at the remote station on nearby Rikers Island. American Airlines employs two on night frequencies, four on day frequencies; Transcontinental and Western Air, two on night, and one on day frequencies; United Air Lines, one day and one night frequency; Eastern Airlines, one frequency; and Pan American Airlines, one frequency.

One receiver is kept on the Army frequency of 4,495 kc and one on the itinerant frequency of 3,105 kc. The receivers are single frequency crystal controlled units with a highly effective

CODAN circuit (carrier operated device antinoise) which operates to block the audio output of the receiver except in the presence of a carrier. Control equipment is provided to turn the receiver on and off, and to indicate by means of a light on the control tower console when the receiver CODAN operates (signal coming in). A submarine cable connects the equipment on Rikers Island with that at the airport proper. One pair in the cable is used for the output of each receiver including the above-mentioned control functions. One pair for each receiver also is used to disable the CODAN circuit at will. One additional pair is used for a wall type magneto telephone to provide communication between the receiver room and the traffic tower.

For reception from planes in the event of failure of a receiver or any of its associated equipment, six tunable receivers, each with provision for crystal control of two frequencies and equipped with crystals, serve as standby equipment.

The transmitters are located in the machine room below the control tower. They are duplicate units, capable of remote operation. One transmitter is connected with the control unit located in the control rack with the receiving amplifiers and control rectifiers; it is linked to the microphone placed over the console and to a jack on the key panel of the control operator's desk. The other transmitter is wired to the microphone and to a jack in the center section of the console. In addition to the overhead microphone, there are two desk stand microphones. All three are equipped with push-to-talk switches functioning as transmitter plate power controls. The receiver switching rectifier is operated by the press-to-talk switches of the remote transmitters so that the local receivers are silenced during transmission.

INSTANTANEOUS BROADCASTING

For instantaneous contact with the communications centers of all airlines at the field, a circuit has been installed in which reception at all points is on loudspeakers until the handset is lifted from the hook. Thus messages from the tower can be broadcast to all points instantaneously.

In the control tower, there is a microphone connection to the airport public address system but no loudspeaker connection. Interference with the many receivers being monitored there is consequently avoided.

Airport Public Address System

The La Guardia Field public address system is an elaborate Western Electric announcing system. Eighty-five loudspeakers in the Administration Building and on the loading platform broadcast announcements which originate at microphones located at fifteen different information centers.

From the control tower, information is conveyed on the arrival time of each flight. From the four ticket counters and information desk in the rotunda of the Administration Building, passengers are paged and the time and place of impending departures are announced. In offices at nine of the fourteen gates of the loading platform, microphones are used for the same purpose and also for calling taxis and porters.

Each microphone is equipped with a press-to-talk switch, and the system includes a relay arrangement which permits the connection of only one microphone at a time.

The specially designed loudspeakers on the loading platform have a 360 degree area of coverage and are arranged so that the output of one blends naturally with the others. The rotunda of the Administration Building is covered by three of the new type Western Electric "cobra" horns mounted in the dome. All other public rooms in the building are reached through wall speakers mounted behind ornamental grilles.

The system employs one type 119-A and two 116-A Western Electric speech amplifiers and four 118-A Western Electric power amplifiers.

Instrument Landing

Since the Bureau of Standards in 1929 produced the first complete experimental instrument system for the landing of airplanes, various solutions of the problem have been attempted. Standardization in any eventuality was recognized as a requisite since coordination of airplane and ground equipment dictated the adoption of a particular system in any one country or in connection with contacts involving international flights.

In line with a request by President Roosevelt, a special Committee of the National Academy of Sciences, in the autumn of 1939, made a thorough study of the problem of standardizing instrument landing equipment. Early in 1940 it submitted a report which cleared the way for the installation of additional systems similar to the experimental and demonstration installation at Indianapolis, known as the Indianapolis System and developed by the International Telephone and Radio Manufacturing Corporation,* under the sponsorship and in accordance with performance specifications of the Civil Aeronautics Administration (C.A.A.).

Subsequent to the special Committee report, additional demonstrations were made to Army, Navy, airline officials and others, and standardization was effected in the sense of "a complete and unified system 'frozen' at a practicable stage of development in order to enable pilots and the industry to start accumulating first-hand knowledge of its technique and operation." In July, 1940, an order was placed by the C.A.A. with the I.T. & R.M. Corporation for the manufacture and installation of instrument landing systems at La Guardia Field, N. Y.; Municipal Airports at Chicago, Cleveland, and Kansas City; Mines Field, Los Angeles, and Meacham Field, Fort Worth.[3, 4, 5, 6, 7]

With the exception of experimental equipment, these landing systems will represent the first commercial installations in the U. S. A. and mark a decided advance in the application of ultra-high frequency radio to aerial navigation. In addition to enhancing the safety of flying, they will relieve congestion at busy airports due to delayed landings under unfavorable weather conditions. The system provides the pilot with complete guidance to the airport runway, both horizontally and vertically. Through beams of ultra-short wave energy transmitted from highly directive equipment at the airport, the pilot by means of a conveniently placed instrument on his instrument panel is provided not only with the exact line of approach laterally to the concrete runway but also with the exact line of descent, when five miles or more away, to the runway so that the airplane settles upon the latter as in normal landing. Further, two "marker beacons" are provided along the line of approach to the landing runway: one indicates to the pilot arrival at a certain point, some distance from the runway, when he should be at a predetermined altitude and in line with the runway as indicated by the landing instruments; the other marker informs the pilot when he passes the boundary of the airport. With these facilities, pilots can land with consistent safety even when weather conditions are extremely difficult.

"Marker" or approach beacons operate at a frequency of 75 megacycles. Separate transmitters and antennas are used for the horizontal and vertical guide beams which are radiated on 109.9 and 93.9 megacycles, respectively.

The frequencies adopted for the C.A.A. (I.T. & R.M.) instrument landing system obviate the possibility of mutual interference between similar installations at different airports. This was found to be a source of difficulty in former systems.

Smaller antenna designs and greater effective directivity are achieved through the application of relatively higher frequency working. Potential obstacle hazards are reduced; and, further, the design permits placement of antennas beyond the danger zone.

Transmitter and antennas for the horizontal guide beam (locating equipment) are in general installed between 150 and 350 meters beyond the end of the runway; alternatively, they may be located below ground level at the edge of the runway. Underground installation does not affect operation other than by slightly reducing the range. Equipment for the vertical descent guide beam is placed some 400 meters to one side of the center of the runway; it cannot, therefore, be regarded as an obstacle.

Installation of a number of these new systems is well advanced and they doubtless will soon be in commercial operation at important airports, including La Guardia Field.

Short Wave Radio Direction Finding on Land

Up to the present time short wave radio direction finding on land in the United States has been confined principally to coast control stations for ocean flights. An advanced type of "azimuth indicating receiver," developed by the Western Electric Co., is now, however, available for operation in the 2.8–6.6 megacycle range, and it is expected that with completion of final tests and refinements now in progress, equipment of this type will find wide application.

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* Formerly International Telephone Development Company, Inc.

This azimuth indicator consists essentially of an antenna collector system, a remote controlled ten-frequency fixed tuned receiver, and a unit combining an azimuth indicating oscilloscope, operating controls, and the necessary voice frequency equipment.

As shown in Fig. 11 the antenna collector system, which is fundamentally of the elevated H fixed Adcock type, and the radio receiver are mounted on an outdoor supporting structure at the actual receiving site. The remote control and indicating unit is shown in Fig. 12 with side panels opened to show auxiliary adjustments.

The system employed is entirely carrier-operated. The collector system extracts the necessary directional information from the incoming carrier wave; this Adcock type of collector, as is well known, provides defense against polarization effects (so-called "night effect" or "airplane effect").[8, 9] In the radio receiver the directional information collected from the antennas is translated into forms suitable for transmission on a two-wire line over a considerable distance to the remote indicator. The radio receiver also places on this two-wire line, which may have an overall attenuation as high as 30 db at 1,000 cycles, whatever intelligence in the form either of speech or tone modulation is imposed on the carrier, and the process of obtaining the bearing does not interfere with the reception of such intelligence.

An outstanding feature of the system is that this two-wire line also is utilized for all remote

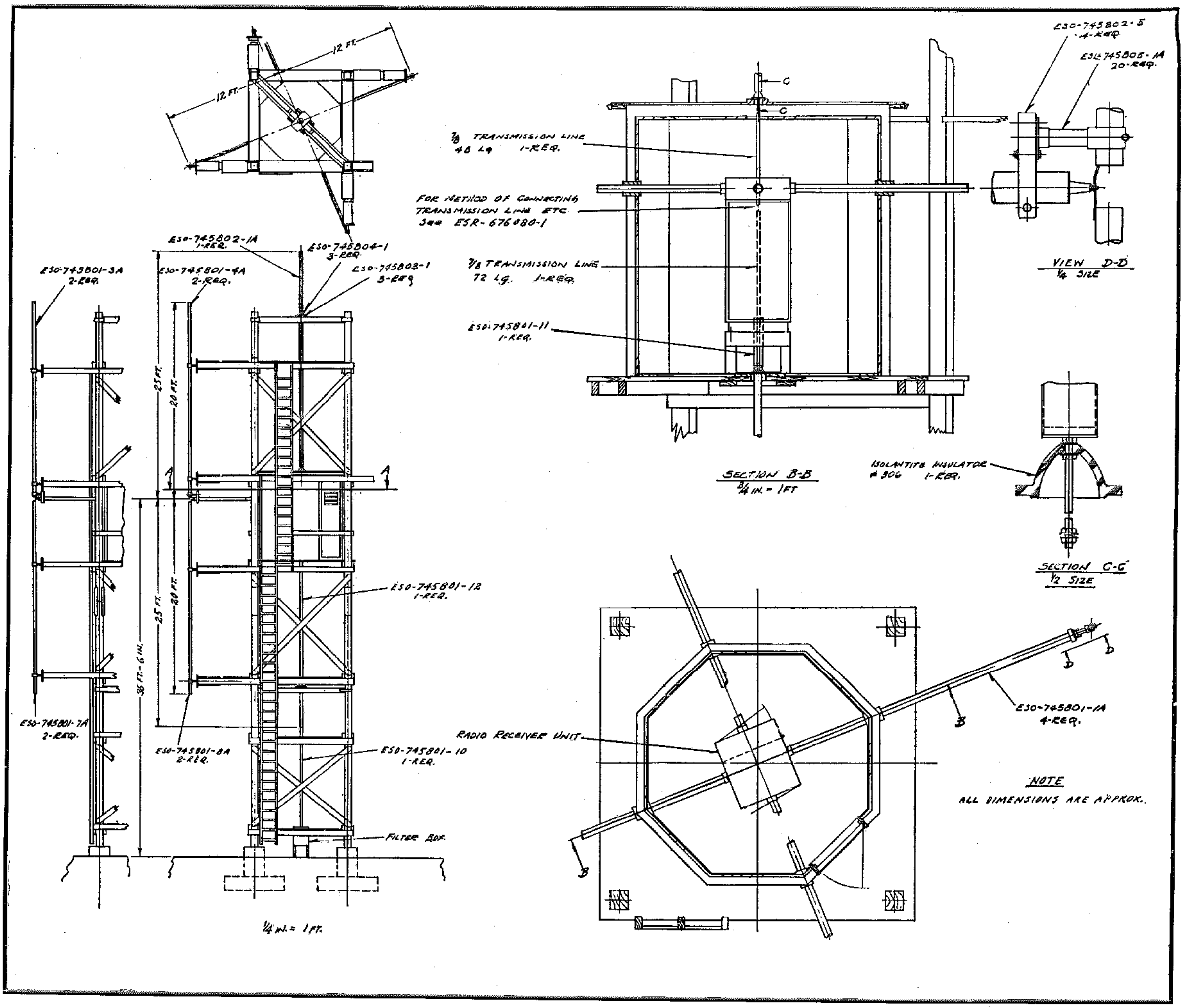
12 FT.
12 FT.
⅞ TRANSMISSION LINE 46 LG 1-REQ.
FOR METHOD OF CONNECTING TRANSMISSION LINE ETC. SEE ESR-676080-1
ESO-745802-1A 1-REQ.
ESO-745804-1 3-REQ.
ESO-745803-1 3-REQ.
⅞ TRANSMISSION LINE 72 LG. 1-REQ.
ESO-745801-3A 2-REQ.
ESO-745801-4A 2-REQ.
ESO-745801-11 1-REQ.
25 FT.
20 FT.
A
A
36 FT.-6 IN.
ESO-745801-12 1-REQ.
ESO-745801-7A 2-REQ.
ESO-745801-8A 2-REQ.
ESO-745801-10 1-REQ.
RADIO RECEIVER UNIT
FILTER BOX
¼ IN.= 1 FT.
C
C
SECTION B-B ¼ IN.= 1FT
ESO-745802-5 4-REQ.
ESO-745805-1A 20-REQ.
VIEW D-D ¼ SIZE
ISOLANTITE INSULATOR #306 1-REQ.
SECTION C-C ½ SIZE
D
D
B
B
ESO-745801-1A 4-REQ.
NOTE ALL DIMENSIONS ARE APPROX.

Fig. 11—Antenna Assembly for Azimuth Indicating Radio Receiver.

control operations involved in frequency and volume selection of the radio receiver and control of a test oscillator at the receiving site.

The indicating device is a cathode ray oscillograph having a 360 degree azimuth scale around the periphery of the screen. In the absence of both signal and noise the light spot is centered with respect to the azimuth scale. As soon as a carrier wave reaches the collector system the spot is radially deflected toward the azimuth indication corresponding to the arrival azimuth of the wave itself with respect to any desired reference, such as true north. The indication is instantly and automatically unilateral, thus eliminating any 180 degree uncertainty. Moreover, and this is one of the most important features of the system, since no mechanical inertia is involved, indications may be obtained on signals of extremely short duration. The position of the spot can easily be read to within two degrees, which is approximately the accuracy of the system when receiving from planes up to a few hundred miles under favorable conditions. Errors of over four degrees are ordinarily rare.

The equipment is considered a medium range, medium accuracy device, but in operation its sensitivity is such that satisfactory indications may be obtained from planes carrying 50 watt transmitters in flight over land at distances up to a few hundred miles in the daytime and evening when transmitting in the 4–6 megacycle band. A few checks have been made on planes using 5 mc when well over 1,000 miles at sea.

The obvious application of a single radio receiver, equipped as described above with an azimuth indicator, located on an airway or at an airway terminal, is to verify that the plane is on course or to obtain an indication of its angular deviation from the course. Alternatively, a single receiver placed in an off-course position may be used to take bearings on a plane and thus indicate its advance along the course. However, there are other possible applications for a single terminally located receiver. It can be used to great advantage in case the pilot, under bad weather or visibility conditions, either becomes confused in the immediate neighborhood of the airport or overshoots the mark. Under such conditions the directional indication, especially in view of its rapidity, can be of great assistance to the ground crew in assisting the pilot to reorient himself for a landing.

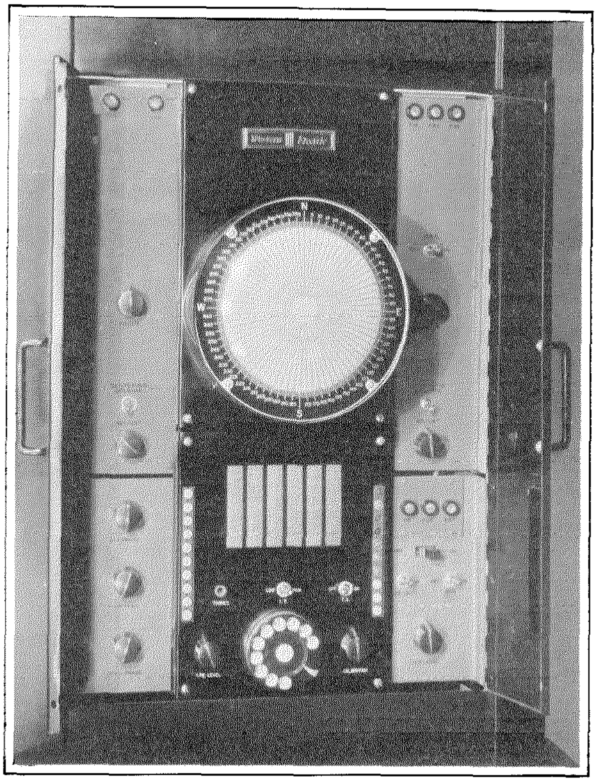

Fig. 12—Remote Control and Indicator Unit Showing Auxiliary Adjustments.

If more than one azimuth indicating radio receiver is available to receive the plane's signals, position determination or triangulation immediately becomes possible, providing the collectors are strategically located with respect to the plane's course.

Several indicators may be operated from a single collector system if multiple indication is required.

Conclusion

The following summarizes typical communication equipment at La Guardia Field, together with indications of the functions involved:

AIRWAYS TRAFFIC CONTROL

Telephones Lines.—To other airports in the New York Control area on a conference basis. To the communications centers of all airlines at La Guardia Field on a ring-answer basis.

Radio Range and Simultaneous Broadcast.—Communication with military and itinerant planes.

Teletype.—Weather reports.

American Airlines

Radiotelephone.—Communication with planes in flight.

Radiotelegraph.—Communication with distant airports not involving heavy traffic.

Teletype.—Communication with airports involving shorter distances and heavy traffic. Flight information relayed from planes to Airways Traffic Control. Network linking ticket, sales, reservations and general offices.

PAX.—Inter-office communications.

PBX.—Inter-departmental communications and connections to local central office exchanges.

Loudspeaker Interphone System.—Serving general offices, communication center, ticket center, agents, air mail and baggage offices.

MUNICIPAL AIRPORT

Control Tower

Radiotelephone.—Simultaneously on 278 kc and on approximately 130 mc for transmission to planes. Reception on various frequencies.

Special Telephone Circuit.—Loudspeaker reception at all airlines communications centers until receiver is lifted.

Public Address.—Microphone connection to the main public address system.

Separate from but closely allied to communications is the problem of airport illumination. An interesting example of a comprehensive illumination and field marker system is the recent Argentine Civil Aeronautic Authority's installation at the Presidente Rivadavia Airport, Province of Buenos Aires.[10] In addition to enhancing the safety of flying, it has effectively reduced air-time distances, particularly in the case of the longer journeys involving the problem of landing early in the morning or late in the afternoon under poor light conditions. Further, inauguration of night flying is under consideration in South America; if introduced, fully adequate airport illuminations, such as the Presidente Rivadavia installation, should prove invaluable.

For aid and suggestions received in connection with the preparation of this article, the author gratefully acknowledges his indebtedness to: Mr. J. G. Flynn, Superintendent of Communications, American Airlines, Inc.; Mr. J. A. Meehan, Acting Chief Engineer, Department of Docks of the City of New York; officials of the Civil Aeronautics Administration; and Mr. Guillermo J. Andrews, Compania Standard Electric, Argentina.

References

1. "Airport P.A.B.X. Network," R. T. Ringkjob, *Electrical Communication*, Vol. 17, No. 3.
2. "A New Unit Type Multi-Frequency 5 Kilowatt Transmitting Equipment," Devereaux Martin, *Electrical Communication*, Vol. 19, No. 4.
3. "Status of Instrument Landing Systems," W. E. Jackson, *Proceedings of Institute of Radio Engineers*, June, 1938.
4. "Plans Cleared for Ten Landing Beams," *Civil Aeronautics Journal*, February 1, 1940.
5. "Indianapolis Landing Aids Demonstrated," *Civil Aeronautics Journal*, April 1, 1940.
6. "The Development of the Civil Aeronautics Authority Instrument Landing System at Indianapolis," W. E. Jackson, A. Alford, P. F. Byrne, and H. B. Fischer. *AIEE Transactions*, Vol. 59, 1940, pages 849–58; *Electrical Communication*, Vol. 18, No. 4.
7. "Ultra-High Frequency Loop Antennae," A. Alford and A. G. Kandoian. *AIEE Transactions*, Vol. 59, 1940, pages 843–8; *Electrical Communication*, Vol. 18, No. 4.
8. "Mountain Effects and the Use of Radio Compasses and Radio Beacons for Piloting Aircraft," H. Busignies, *Electrical Communication*, Vol. 19, No. 3.
9. "Evaluation of Night Error in Aircraft Direction Finding," H. Busignies: Paper presented at I.R.E. Summer Convention, Detroit, Michigan, June 23, 1941.
10. "Illumination of Presidente Rivadavia (Moron) Airport (Province of Buenos Aires)," Primitivo B. Padilla and E. T. G. Palmer, *Electrical Communication*, Vol. 19, No. 4.

Rotary Automatic Telephone Service in Lima, Peru

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and
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Introduction

THE Republic of Peru, situated on the west coast of South America, has a total area of 1,300,000 square kilometres and a population of more than 6,500,000. Lima, the capital, comprising over half a million inhabitants, was founded on January 18, 1535, by the Spanish Conquistador Francisco Pizarro, who named it "City of the Kings" in honor of the Spanish monarchs Ferdinand and Isabella. Lima today is a modern metropolis in which the beauty and historic interest of the colonial structures blend with the convenience and utility of modern avenues and buildings. Its growth during the last twenty years has been rapid so that the small towns of San Isidro, Miraflores, Barranco, Chorrillos and San Miguel, which formerly constituted entirely separate communities, are now merged as suburbs of Lima, forming a single urban area extending from the foothills of the Andes to the shores of the Pacific. Only twelve kilometres distant from Lima, is the city of Callao, the principal port of Peru, with a population of about 82,000.

Although the latitude of Lima is about 12° south, well within the tropical zone, the average temperature is 18.6°C.; the rainfall is only 3.3 millimetres a year, but the relative humidity is high, averaging 85.6% and frequently approaching 100%. This high humidity is one of the chief enemies of the telephone man who must devote constant attention to preventive maintenance in order to minimize low insulation troubles on all types of plant.

Conversion to Automatic

In 1930, when the Compañia Peruana de Telefonos Limitada became associated with the International Telephone and Telegraph Corporation, Compañia Peruana furnished telephone service in the Lima area through manual central offices in Lima, Callao, Miraflores, Barranco, San Isidro, Magdalena Vieja and Madgalena del Mar. Initial installations of 7-A.1 Rotary equipment, however, had been started in two offices, namely, Washington (in the downtown area of Lima) and Miraflores.

The new management of the company completed the installation of the 7-A.1 equipment in Washington and Miraflores. The first cutover was effected in December, 1930, part of the southern section of Lima being transferred to the new Washington office. In November, 1931, the Miraflores office was opened, replacing an antiquated magneto switchboard. Concurrently, plans were formulated for an enlarged construction program with a view to providing automatic service throughout the area and, at the same time, renovating the existing outside plant.

Fig. 1 shows the general layout in the Lima area and the location of the central offices. The numbering arrangement is based on a standard 7-A type Rotary scheme for a 5-digit system and a capacity of 50,000 numbers. All odd levels, 1, 3, 5, 7 and 9, of the first group selectors are used as local levels, each corresponding to 2,000 lines; even levels, 2, 4, 6 and 8, correspond to units of 10,000 lines, while level 0 is reserved for special services. The numbers allotted to the sub-offices are taken in blocks of 2,000 from the numbers assigned to the corresponding main office. In the case of San Isidro and Barranco sub-offices, one level of the second group selectors is used for special service so that the numbering capacity is reduced from 4,000 to 3,800. Thus, with the present layout, the Lima area has an ultimate capacity of 49,600 lines distributed as shown by the following table:

Office Name	Type	Lines Installed	Numbering
Washington I	7-A.1 main office	4000	10000–13999
San Isidro	7-A.2 sub-office	1000	14000–17799
Magdalena	7-A.2 sub-office	600	18000–19999
Washington II	7-A.2 main office	9000	30000–39999
Washington III	7-A.2 main office	—	70000–79999
Callao	7-A.2 main office	1600	90000–99999
Miraflores	7-A.1 main office	2800	54000–59999
Barranco	7-A.2 sub-office	1000	50000–53799

The Lima city area is served from the main Washington office which has an ultimate capacity for 30,000 lines of 7-A.2 equipment. The old section of the building housing 4,000 lines of 7-A.1 equipment, general stores and miscellaneous offices is constructed mainly of brick and adobe. For economic reasons it was decided to retain this building initially and to erect adjacent thereto a ferro-concrete earthquakeproof building to accommodate the first 10,000 line 7-A.2 unit, special service equipment and general offices for the staff of the telephone company. The old section of the building was reinforced to minimize risk of damage in the event of an earthquake; also the facade was reconstructed to line up with that of the new building. The appearance of the present structure is shown by Fig. 2, the old section being at the extreme right. Ultimately the older portion will be demolished and the ferro-concrete structure extended to accommodate three 10,000 line 7-A.2 units. The 30,000 line capacity of the Washington office includes two sub-offices at San Isidro and Magdalena with a capacity of 3,800 and 2,000 lines, respectively.

The Callao office (Fig. 3) serves the port district and surrounding residential suburbs of La Punta, Bellavista and La Perla. It is an integral part of the Lima flat rate area with direct trunks to other offices over 19 and 22 gauge cable pairs graded and loaded in accordance with supervision and transmission requirements.

The third main office serves the Miraflores residential district; the ultimate capacity is 9,800 lines, including 3,800 lines of 7-A.2 equipment in the Barranco sub-office. The plan is to transfer the 4,000 lines of 7-A.1 equipment from Washington to Miraflores in stages in accordance with growth requirements. Thus all 7-A.1 type equipment will be concentrated in one office (Miraflores) and all other offices will be 7-A.2 type.

Sub-offices

The sub-offices were designed for use in outlying districts where the ultimate demand will

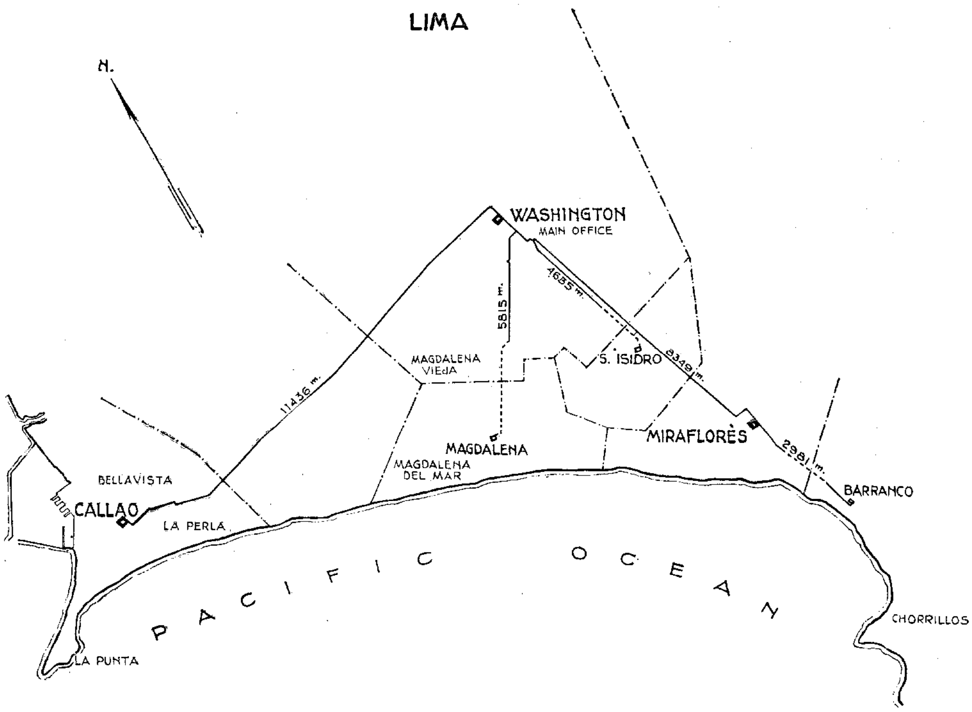


Fig. 1—Location of Central Offices in the Lima Area.

Fig. 2—Washington Automatic Exchange and Headquarters Building of the Compañía Peruana de Teléfonos Limitada.

not exceed 3,800 lines and the local community of interest is comparatively high. Since this type of sub-office is not in common use, a short description of the main operating procedure is given.

An originating call engages a link and register at the sub-office followed by a cord circuit and register at the main office. Dial tone is received over the junction to the main office. Dial impulses sent by the calling subscriber are received by the registers in the sub-office and at the main office.

In the case of a local call the junction to the main office is released and the connection is established via a fourth group and final selector under the control of the local register. The local fourth group selector is similar to the regular 7-A.2 fourth group selector used in the main office but is provided with a transmission bridge and controls the release of the connection.

When the call is not local, the register at the sub-office is released and the connection is established under the control of the register at the main office.

The register at the sub-office is designed for use either in 5 or 6-digit areas and will discriminate between one or two groups of 2,000 numbers. When only one group of local fourth selectors is installed, the level of the junction finder corresponding to the second group is used for special services, so that the capacity is for 2,000 numbers. When two groups of local fourth selectors are required, one level must be reserved for special services and thus the ultimate capcaity is reduced to 3,800 lines.

If all junctions to the main office are engaged, dial tone is given from the local register. A local call may be completed but, in the case of a call directed to another office, busy tone will be given by the local register.

Calls to special services not requiring a high

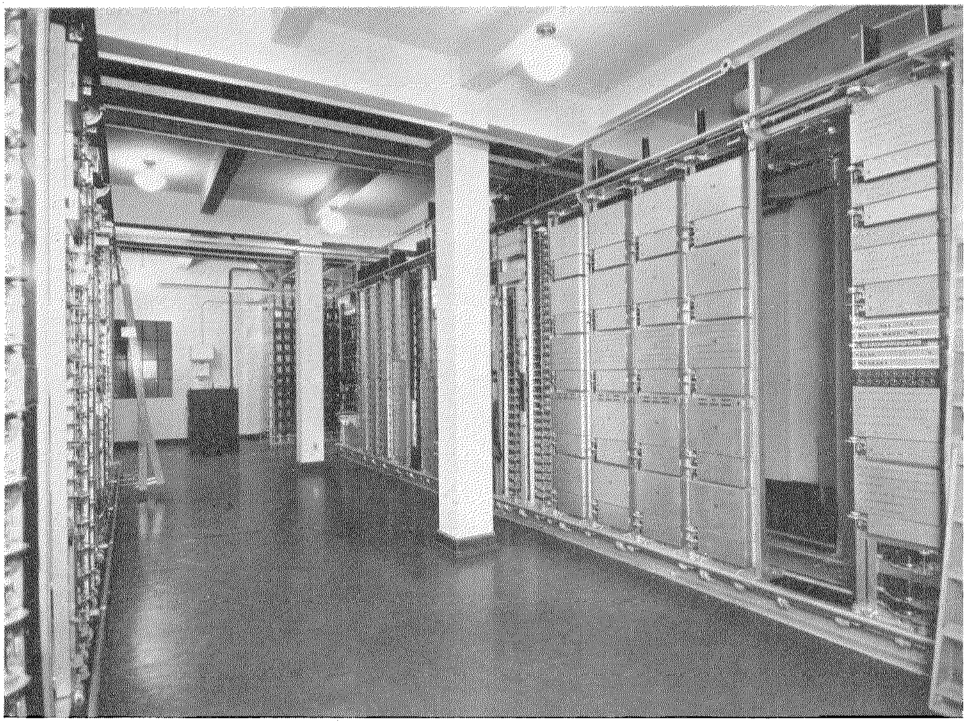


Fig. 3—7-A.2 Rotary Equipment in the Callao Exchange. Main Distributing Frame and Test Desk Are in the Rear.

efficiency junction or metallic through connection are routed via the common group of junctions to the main office. On calls to the toll board the local register breaks down the connection to the main office and routes the call via a group selector giving access to junctions which terminate on the toll board. Depending upon the class of the calling subscriber, levels may be selected giving access to junctions for non-restricted, restricted or coin box lines.

Incoming calls are completed via fourth group and final selectors, similar to those in the main office, except that the fourth selector contains a transmission bridge and arrangements for holding the connection over a 2-wire junction.

The sub-offices are not normally attended. With existing equipment not exceeding 1,000 lines, routine visits for maintenance inspection twice a week are found sufficient. Means are provided for extending fault alarms to the main office.

Centralized Special Services

All special services for the Lima area including toll, assistance, information, interception, service observation, repair and testing are concentrated in the main office at Washington.

While the Compañia Peruana de Telefonos Limitada owns no toll circuits with the exception of short haul circuits to the resort towns of Chosica and Ancon about 45 kilometres from Lima, subscribers can communicate with many of the provincial towns in Peru and with other telephone systems throughout the world by means of interconnection with the network of the Compañia Nacional de Telefonos del Peru and the facilities of All America Cables and Radio Incorporated. This service is handled on a 6-position No. 3 type toll switchboard.

The test bureau comprises a 3-position repair desk operated in conjunction with a 5-position test desk. Reports from subscribers regarding physical plant troubles and actual or potential faults observed by the company's employees are routed direct to the repair desk via level 02, where they are recorded and passed to the test desk for immediate attention. The test desk is equipped with jack-ended trunk circuits giving access to test final selectors in each office. By means of a high speed key set the test clerk may set up via these circuits a metallic through connection to any subscriber's line. Incoming trunks from level 01 terminating on the test desk are arranged so that when a repair man dials this code from any subscriber's station a metallic through connection is established and the line may be tested without any further switching operation.

Subscribers' requests for assistance on account of service difficulties not involving physical plant troubles or emergency calls for public services, such as fire, ambulance or police, are routed via level '00' to an assistance operator on the toll board. The assistance operator has facilities for extending calls and for verifying the condition of any subscriber's line in the case of double number, 'don't answer' or 'busy' complaints.

Directory information service is handled on a 4-position desk comprising two double-sided tables equipped with key-ended trunks from level '03.' This desk is equipped with rotary files providing the operators with speedy access to the required information.

Interception services are handled on a 4-position test desk similar to and lining up with the directory information desk. Dead levels in automatic offices are connected to special circuits and calls made in error to such levels are routed to key-ended trunks on the interception desk. If a subscriber dials a number which does not exist in the Lima numbering scheme, the register automatically directs the call to the interception desk. To care for disconnections and changed numbers between directory issues, any subscriber's line may be connected to a changed number circuit arranged so that all calls to this line are directed automatically to the interception desk.

A 2-position observation desk is provided, the main function of which is to furnish facilities for observing the class of service being given from the subscribers' point of view. Observation circuits are provided giving access over one trunk to a group of subscribers' lines, and arranged so that the operator may identify the calling line, record the called number, etc. Facilities also are included for holding a faulty connection and speaking to the subscriber under observation; these facilities are used only for instruction purposes or when making special observations, the results of which are not included in the general reports.

A special unit is provided for 200 coin box lines in Washington and in Callao. At the present time, automatic prepayment single slot coin boxes for local service are used. The coin is collected when the called party answers or, in the case of an ineffective call, it is refunded when the calling party replaces the receiver. Calls to the toll board from a coin box are directed to a separate group of junctions appearing before the assistance operator, so that this operator may advise the calling party that coin boxes are barred from toll service or, if necessary, may complete the call; in this case, collection or refunding of coins is under the control of the operator. Fig. 4 illustrates the general arrangement of the toll and special service operating room located in Washington.

Power Plant

In the main offices, power plants are operated on a full float basis using shunt generators and automatic voltage regulators. The starting and stopping of the machines is controlled manually. Connections between batteries, power board and and machines are overhead; bare copper bars are used for the main circuits. This minimizes risk of breakdown in the event of damage to the building due to earthquake disturbances and facilitates repair if the plant is damaged. Permanent emergency plants are provided of sufficient capacity to maintain the office in service in the event of failure of the main supply. In Washington the emergency plant comprises a Diesel engine coupled to a generator with an a-c output which can replace the main supply to the battery charging machines, ringing machines, switchrack motors and lighting circuits. In Miraflores and in Callao the emergency plant comprises a gasoline engine coupled to a generator with a d-c output for charging the batteries and operating the duplex switchrack motors.

In sub-offices, power plants are operated on a 10% discharge routine under the control of ampere-hour meters with automatic voltage regulation. No permanent emergency power plant is provided but, in the event of failure of the main supply, the three offices may be maintained in service by means of a portable machine comprising a gasoline engine coupled to a d-c generator complete with control panel for battery charging. This machine is mounted on a trailer which can be towed to any office as required and placed in service on short notice.

Personnel Problem

When the enlarged construction program was undertaken, only a skeleton staff of competent supervisors was available so that one of the principal problems which had to be met was the recruiting and training of local personnel to undertake the construction and, subsequently, the maintenance of the new plant. The company engaged a number of recent graduates from technical schools for the purpose of preliminary training in the theory and practice of telephone work. Thus, by the time the first consignment of 7-A.2 equipment for Washington had arrived in Lima a crew of apprentice installers was available with a satisfactory knowledge of the fundamentals, including cable color codes, technique of soldering, trimming cables and mechanical adjustment of equipment. While instruction classes in the theory of circuits, switch adjustments and localization of troubles were continued, the students were employed on the installation of the equipment. Very satisfactory results were obtained and the first installation of 5,800 lines of 7-A.2 equipment was completed without difficulty by a local staff, which lacked previous knowledge of telephone equipment, under the control of one installation supervisor assisted by one experienced switch adjuster. During the course of the installation work a careful selection was made of the men who had shown the greatest aptitude; they were given special training in testing and other phases of maintenance work. By the time that the new Washington office was cut into service a nucleus of maintenance men was available, sufficiently expert to carry out routines and localize faults. This plan of training the staff on the job combined with instruction classes has been continued for all branches of maintenance and construction work with very satisfactory results.

Earthquake Precautions

Lima being situated in a zone subject to earthquakes, special precautions were necessary with respect to the type of building construction and method of equipment installation adopted.

The buildings are constructed on the basis of a rigid framework of reinforced columns and beams. The outside walls comprise panels of reinforced concrete between the main columns. The inside walls are of light hollow tile. The complete buildings may be considered as boxes of reinforced concrete which may vibrate as a whole but which will not change their shape when an earthquake occurs.

The vertical channels of the switchracks as supplied by the factory were extended about 50 centimetres. These extension details were then connected together by steel 'U' beams and secured to a main steel framework, in turn fixed to the building columns. The switchracks and superstructure consequently form a solid framework fixed to the main building columns.

1940 Earthquake

On the 24th of May, 1940, at 11:35 in the morning, a violent earthquake totally destroyed the suburb of Chorrillos and caused extensive damage throughout the remainder of the city. During a period of 65 seconds a series of strong tremors caused many old buildings to collapse and seriously damaged those of more modern construction. The worst damage was in the port district of Callao and in the residential district of Chorrillos, particularly in the latter, where practically the entire population was left homeless. In Lima city, the most serious damage occurred in the central district where most of the old buildings, many dating from colonial times, are located. Some of the old churches suffered considerably, notably the church of Santo Domingo, the forty-metre spire of which was completely destroyed.

As a result of the precautions taken in the construction of the telephone buildings, the robust-

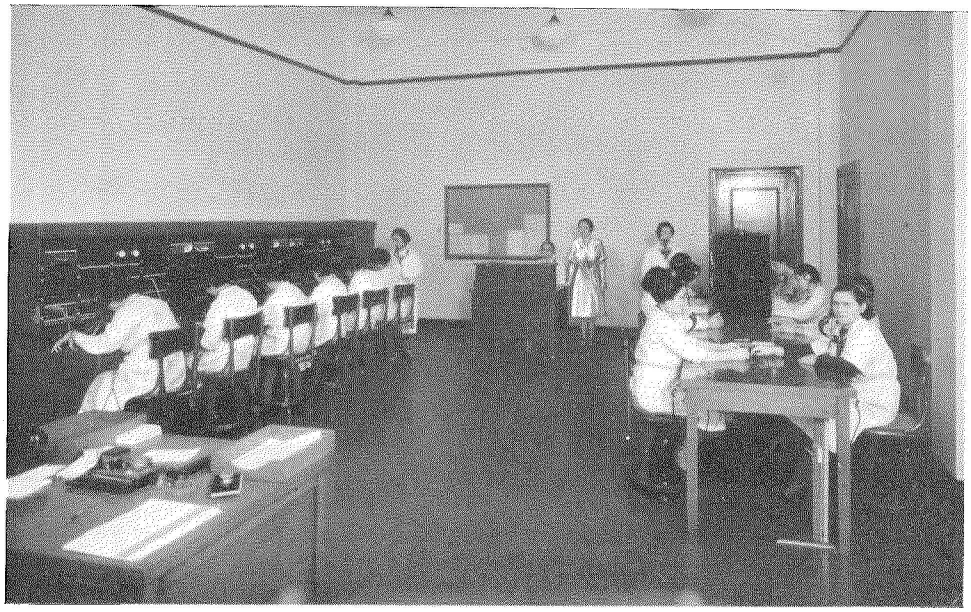
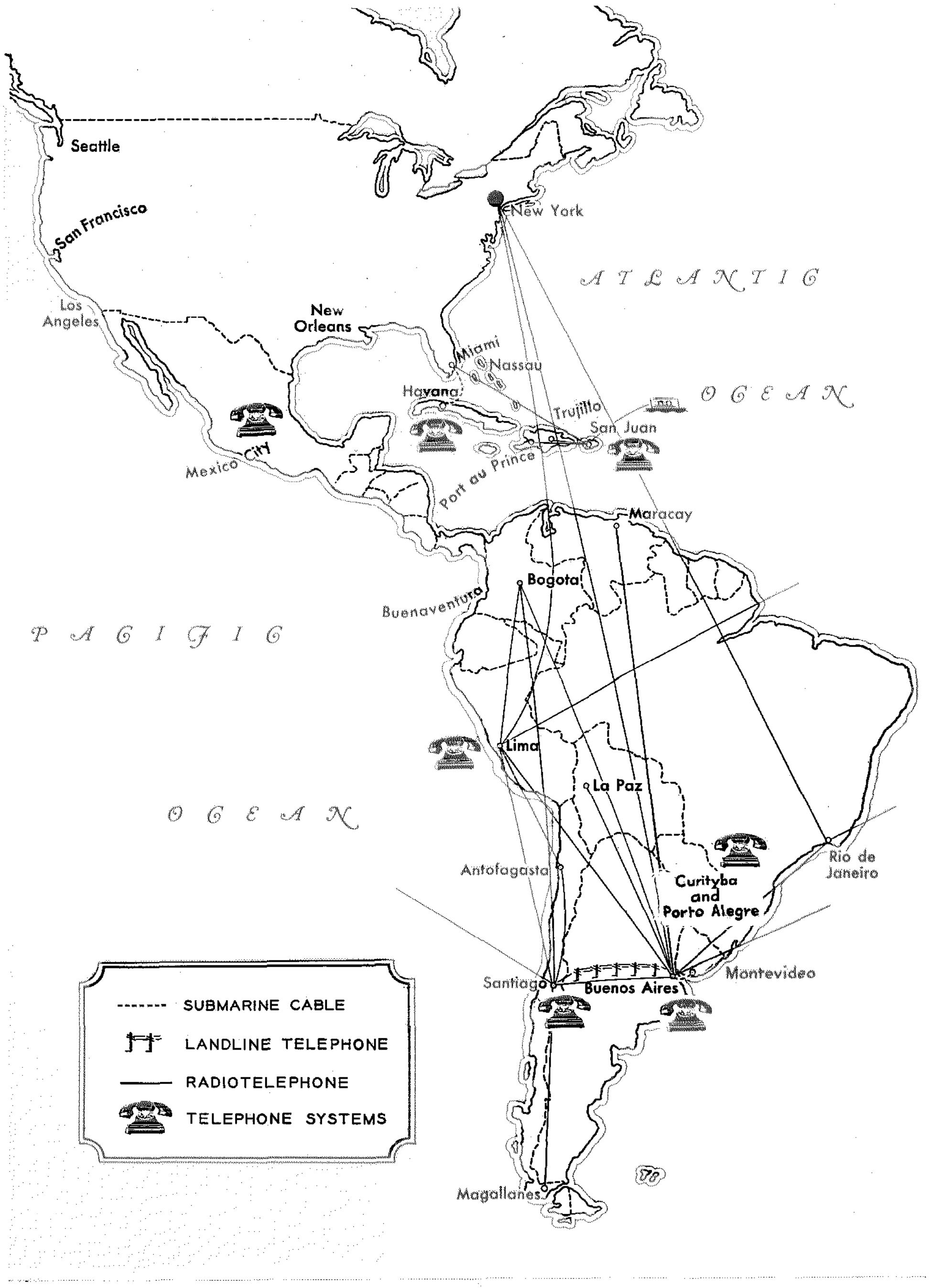


Fig. 4—Toll and Special Service Operating Room in the Washington Exchange.

ness of the Rotary machine switching equipment and the method employed in installation, there was no interruption in the telephone service even during this major disaster. Damage to the central office buildings was limited to cracks in the old portion and to the ornamental parapet of the Washington building. The reinforced concrete structures suffered no damage whatever and the equipment continued to function normally during and after the earthquake. About 2,000 telephones were put out of service, including those due to buildings completely or partially destroyed or to damaged distribution cables. The traffic overload for several hours following the earthquake was very heavy due to the large number of people who attempted to use the telephone to communicate with their homes; also, because of the large number of permanent loops caused by damaged distribution plant, or telephones shaken from tables. Despite these abnormal conditions, no service interruptions occurred in so far as the central offices were concerned although, of course, dial tone delay was considerable, at one time exceeding two minutes. As a result of the excellent work of the local staff, adequate facilities for communication with the most seriously damaged areas were established rapidly and proved of very great value in connection with relief work. The effective aid thus rendered by the telephone company was the subject of special commendation by the authorities.


Seattle
San Francisco
Los Angeles
New Orleans
New York
ATLANTIC
OCEAN
Miami
Nassau
Havana
Trujillo
San Juan
Mexico City
Port au Prince
Maracay
Bogota
Buenaventura
PACIFIC
OCEAN
Lima
La Paz
Antofagasta
Curityba and Porto Alegre
Rio de Janeiro
Montevideo
Santiago
Buenos Aires
Magallanes
------- SUBMARINE CABLE
LANDLINE TELEPHONE
——— RADIOTELEPHONE
☎ TELEPHONE SYSTEMS

Telephone Circuits of I. T. & T. Operating Companies which provide the channels for national and international broadcasts.

Western Hemisphere Broadcast Networks

President Roosevelt's Fireside Chat of May 27, 1941

By JOHN W. G. OGILVIE
International Telephone and Telegraph Corporation, New York, N. Y.

SINCE radio broadcasting has reached a stage where its unique influence as an educational and cultural medium can no longer be questioned, private organizations largely responsible for its development under governmental regulation are becoming increasingly aware of their responsibility in fostering the Western Hemisphere ideals of democracy and mutual understanding. Consequently, in the past few years, international broadcasts originating in the Americas have become more frequent and interchanges of North and South American programs are a daily occurrence. Fortunately, in these broadcasts the handicap of time difference is present only to a minor degree, and English, Portuguese and Spanish are not unfamiliar to many listeners.

National or international programs to be effective must be available to all having broadcast receiving sets and reception must be reasonably free from static interference; further, listener interest must be aroused either by anticipatory interest based on past experience or suitable advance notice of appealing programs. These requirements are not met by powerful short wave broadcasts because of their hit and miss coverage, lack of adequate short wave receiving sets, etc.

Wide dissemination of programs of this character thus can be effected only through local medium wave broadcast stations to which every radio set owner is a potential listener. For adequate national or international hookups, furthermore, local stations must be served by high quality wire networks or radiotelephone circuits (inter-linked radio stations). It is, accordingly, a happy circumstance that the International Telephone and Telegraph Corporation, primarily due to its activities in developing local, national and international communications in the Southern continent, has at its disposal both wire networks and national and international radiotelephone stations for providing program transmission service to the broadcast stations in many of the important countries in the Western Hemisphere.

An outstanding instance of the potential scope of these facilities was presented by President Roosevelt's Fireside Chat of May 27th from the White House, Washington, D. C., in which he declared an unlimited national emergency. Members of the Diplomatic Corps representing American Republics in Washington, together with their families, were among the President's personal guests.

South American transmission in Spanish was effected over the radio circuit from New York to Buenos Aires where it was fed to an Argentine network through the lines of the United River Plate Telephone Company. From Buenos Aires, the program was conveyed to Uruguay via the submarine cable across the Rio de la Plata laid by I. T. & T. associated companies in 1928. Chilean broadcasting stations participated, both by means of the Buenos Aires-Santiago radio link and the transcontinental line and cable across the Andes Mountains. Bolivia received the program over the radiotelephone circuit from Buenos Aires, as did Bogota, Colombia, and Lima, Peru.

The President's message in Portuguese was transmitted over the New York-Rio de Janeiro radio circuit and was distributed to the entire Brazilian network. Transmissions to stations outside of the Rio de Janeiro and Sao Paulo areas were effected through short wave facilities of the I. T. & T. associated company in Rio de Janeiro.

Reports confirmed the excellent transmission quality and the interest evoked by the address. The South American network, giving coverage to an estimated ten million listeners, was the most comprehensive ever established on that continent for a single program originating in the U. S. A.

Plant Facilities of the Mackay Radio and Telegraph Company in the New York Area

By HARADEN PRATT

Vice President and Chief Engineer, Mackay Radio and Telegraph Company, New York, N. Y.

Historical

THE Mackay Radio and Telegraph Company first commenced the construction of its radio communication facilities at New York in 1928. Prior to that time, its operations had been confined to the Pacific Coast where its predecessor, the Federal Telegraph Company, in 1910, had inaugurated public domestic radiotelegraph and ship-to-shore services.

The famous old radio station, call letters WSL, built by a German company in 1911 near Sayville, Long Island, and enlarged by the U. S. Government in 1918, was leased from the Navy Department as the nucleus for a transmitting station. Property was acquired near Southampton, L. I., for receiving purposes, and a Central Operating Department was established at 20 Broad Street, New York, N. Y.

The first public service to be opened was ship-to-shore. It was established early in 1929, using transmitters installed at Sayville, receiving and operating facilities at Southampton, and a small harbor marine station located on the roof of the 20 Broad Street building. Various other public services were opened from time to time: to South America, the West Indies, Central America, Europe, and points within the United States.[1] The entire present day Mackay Radio System is shown diagrammatically in Fig. 1.

In 1931, the International System decided to locate the Operating Departments of its Cable and Radio Companies at 67 Broad Street, New York, in the International Telephone Building.

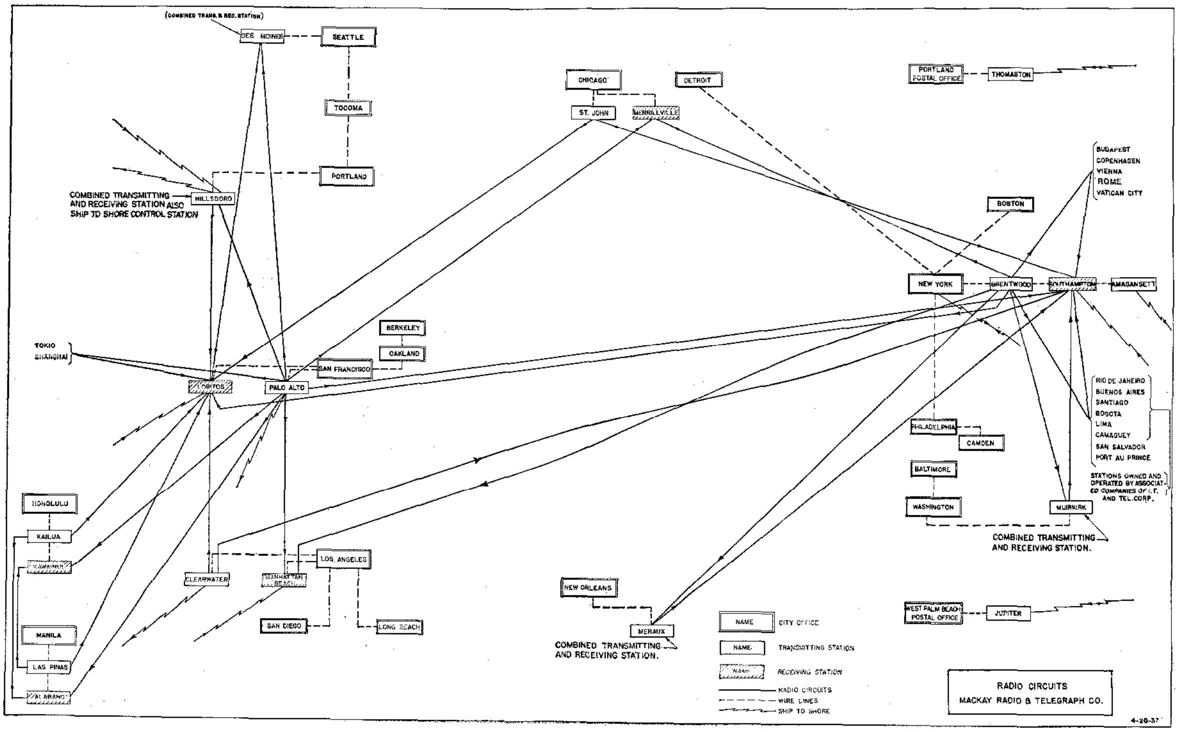

(COMBINED TRANS. & REC. STATION)
DES MOINES
SEATTLE
TOCOMA
PORTLAND
COMBINED TRANSMITTING AND RECEIVING STATION ALSO SHIP TO SHORE CONTROL STATION
HILLSBORO
TOKIO
SHANGHAI
BERKELEY
OAKLAND
SAN FRANCISCO
LOBITOS
PALO ALTO
HONOLULU
KAILUA
KAWAINUI
CLEARWATER
MANHATTAN BEACH
LOS ANGELES
SAN DIEGO
LONG BEACH
MANILA
LAS PINAS
ALABANG
CHICAGO
ST. JOHN
MERRILLVILLE
DETROIT
PORTLAND POSTAL OFFICE
THOMASTON
BUDAPEST
COPENHAGEN
VIENNA
ROME
VATICAN CITY
BOSTON
NEW YORK
BRENTWOOD
SOUTHAMPTON
AMAGANSETT
RIO DE JANEIRO
BUENOS AIRES
SANTIAGO
BOGOTA
LIMA
CAMAGUEY
SAN SALVADOR
PORT AU PRINCE
STATIONS OWNED AND OPERATED BY ASSOCIATED COMPANIES OF I. T. AND TEL. CORP.
PHILADELPHIA
CAMDEN
BALTIMORE
WASHINGTON
MUIRKIRK
COMBINED TRANSMITTING AND RECEIVING STATION.
NEW ORLEANS
MERAUX
COMBINED TRANSMITTING AND RECEIVING STATION.
NAME CITY OFFICE
NAME TRANSMITTING STATION
NAME RECEIVING STATION
RADIO CIRCUITS
WIRE LINES
SHIP TO SHORE
WEST PALM BEACH POSTAL OFFICE
JUPITER
RADIO CIRCUITS
MACKAY RADIO & TELEGRAPH CO.
4-20-37

Fig. 1—Radio Circuits of Mackay Radio and Telegraph Company.

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[1] "The Mackay Radio and Telegraph Company Communications System," M. H. Anderson, *Electrical Communication*, Vol. 19, No. 4.

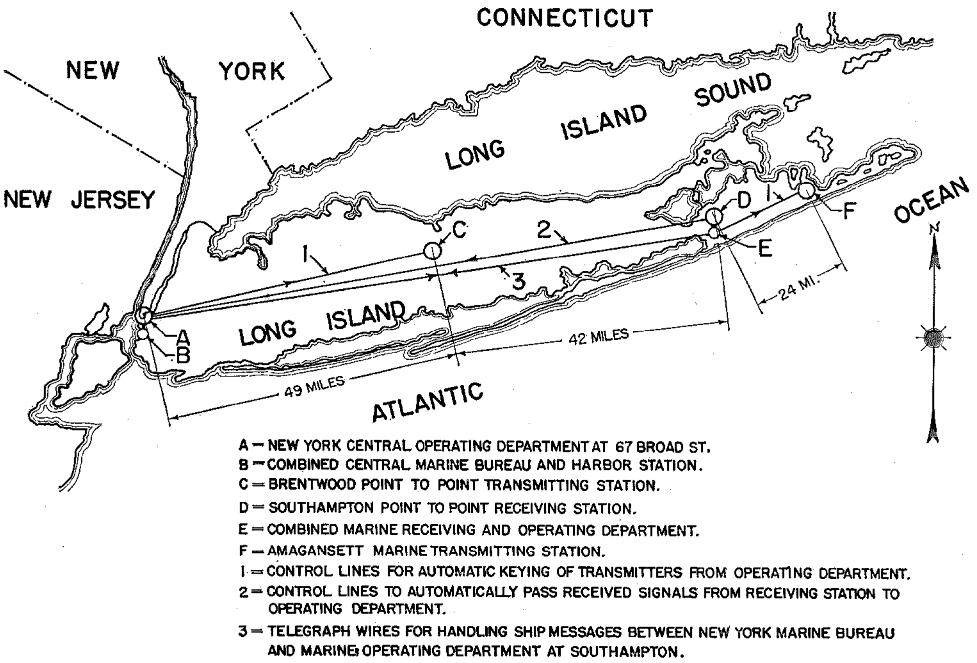

CONNECTICUT
NEW YORK
NEW JERSEY
LONG ISLAND SOUND
LONG ISLAND
ATLANTIC OCEAN
N
A
B
C
D
E
F
1
2
3
49 MILES
42 MILES
24 MI.
A — NEW YORK CENTRAL OPERATING DEPARTMENT AT 67 BROAD ST.
B — COMBINED CENTRAL MARINE BUREAU AND HARBOR STATION.
C = BRENTWOOD POINT TO POINT TRANSMITTING STATION.
D = SOUTHAMPTON POINT TO POINT RECEIVING STATION.
E = COMBINED MARINE RECEIVING AND OPERATING DEPARTMENT.
F — AMAGANSETT MARINE TRANSMITTING STATION.
1 = CONTROL LINES FOR AUTOMATIC KEYING OF TRANSMITTERS FROM OPERATING DEPARTMENT.
2 = CONTROL LINES TO AUTOMATICALLY PASS RECEIVED SIGNALS FROM RECEIVING STATION TO OPERATING DEPARTMENT.
3 = TELEGRAPH WIRES FOR HANDLING SHIP MESSAGES BETWEEN NEW YORK MARINE BUREAU AND MARINE OPERATING DEPARTMENT AT SOUTHAMPTON.

Fig. 2—Mackay Radio Stations and Operating Organizations in the New York Area.

Mackay Radio, consequently, constructed and placed in operation, during the latter part of that year, a new and improved Central Operating Department with space adequate for expansion to meet future growth. This department was located on the same floor with the Operating Departments of the Commercial Cable Company and All America Cables, Inc., all three being interconnected by message carrying belts and pneumatic tubes. The small harbor marine radio station was also moved to 67 Broad Street at the same time.

Due to the high attenuation of radio waves in the intermediate frequency band (near 500 kc) over Long Island ground, the operation of the ship-to-shore service, using the transmitters at the Sayville station, was found to be unsatisfactory. A new transmitting station for ship-to-shore operation was constructed near Amagansett, L. I. (Napeague Harbor), and placed in operation in 1932. Here, because of close proximity to Long Island Sound on one side and the Atlantic Ocean on the other, losses due to ground absorption were negligible.

By the year 1933, the operations of the Company became sufficiently extensive to make necessary the construction of a new transmitting station, since the small size of the Sayville property restricted possibilities for expansion. In July 1934, construction was started on a new transmitting station, near Brentwood, L. I., where an 1100 acre site was acquired. In 1936, the Sayville station was discontinued, all point-to-point and shore-to-ship transmitters having been transferred to the new Brentwood and the Amagansett stations, respectively. The latter was enlarged to accommodate all transmitters for the ship-to-shore service.

To meet the Company's growing requirements, the receiving station property at Southampton was also extended and a new building erected, equipped and placed in operation in 1935 for the point-to-point services.

For some years the Company carried forward

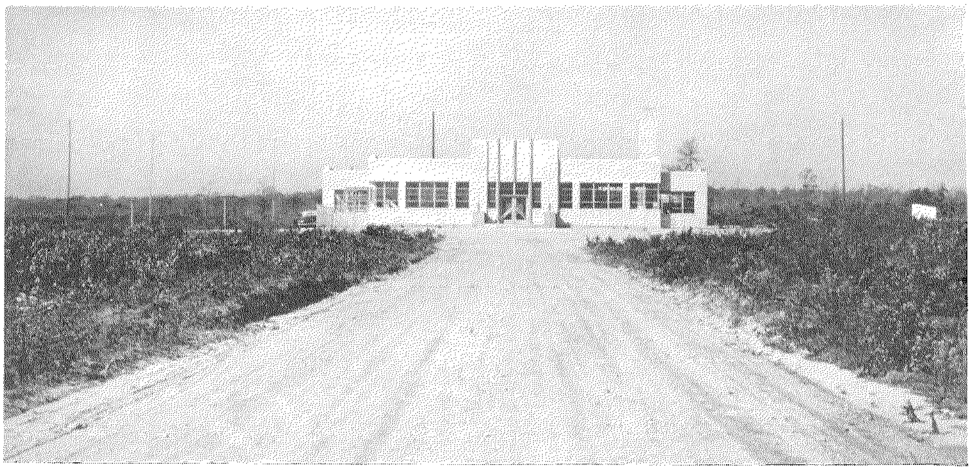


Fig. 3 A—Brentwood Transmitting Station, Main Building.

development work on a remote control system for conveying signals automatically between the Central Operating Department in New York and the transmitting and receiving stations, utilizing ultra-high frequency radio circuits in place of leased wire lines. Such a system was established and has been in successful operation for the past few years; it is, in fact, being expanded. At the present time, it is used for the control of all transmitters at Brentwood, and for a portion of the channels used to carry received signals from the Southampton receiving station to New York. Radio frequencies in the 100 megacycle region were first utilized. New allocations by the Federal Communications Commission required the rebuilding of the system in 1939 for frequencies near 135 megacycles; in 1940, the Commission again made new allocations, requiring another rebuilding to permit the utilization of frequencies near 160 megacycles.

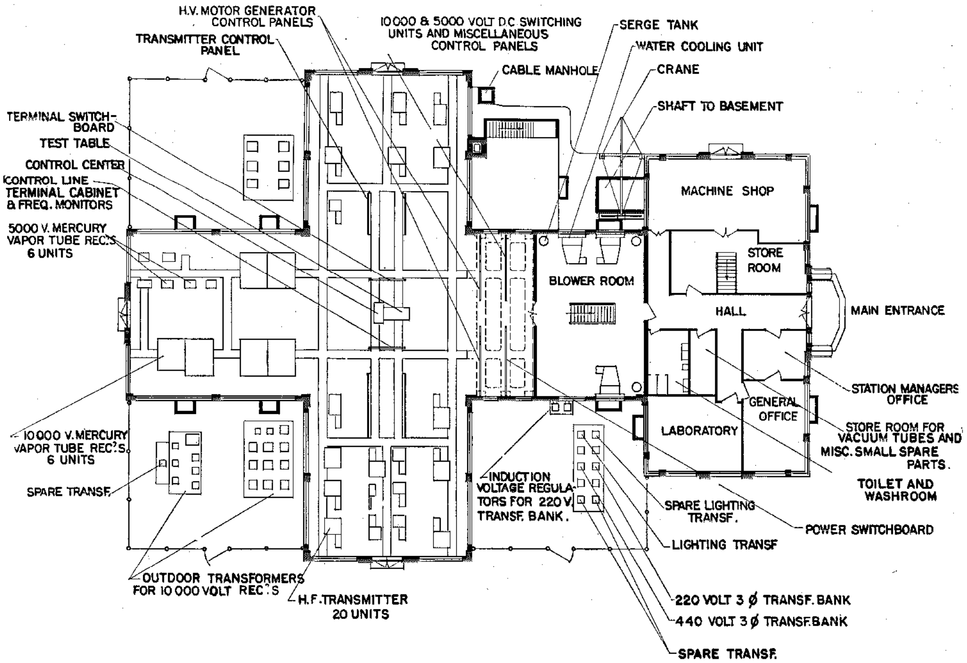
Fig. 2 indicates the stations and operating organizations in the New York area and their interrelation.

Brentwood Transmitting Station

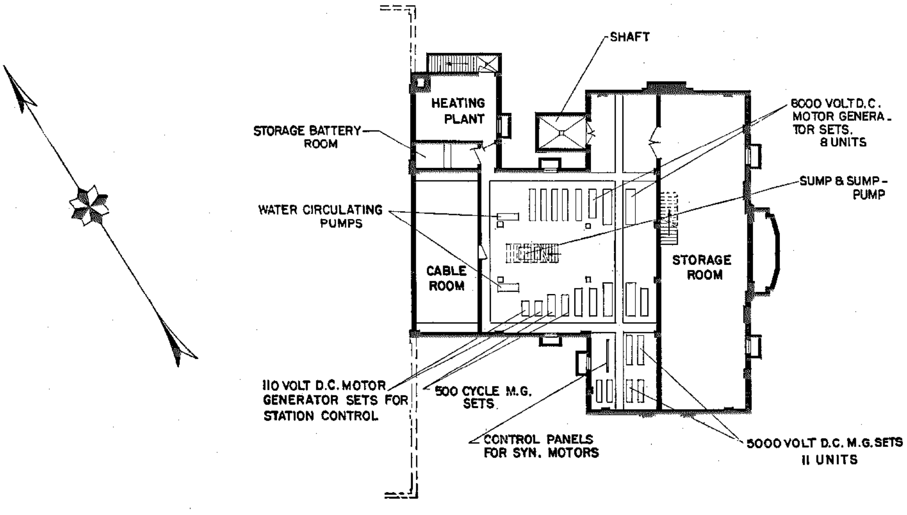
This property is situated near the center of Long Island north of the town of Bayshore. Here is located the main building (one story with basement) and auxiliary structures for the power substation, ultra-high frequency receiving apparatus, pump house, garages and storage sheds.

The main building and a floor plan are shown in Figs. 3 A and B. It houses 22 high frequency transmitters, ranging from 10 to 50 kw output (except one 2 kw unit), and all auxiliary apparatus. Direct current power for the anodes of amplifier tubes is supplied by 23 motor driven generators, ranging in output capacity from 3 kw at 3000 volts to 20 kw at 8000 volts, four small rectifiers at 3000 volts and six large rectifiers at 10,000 volts. Total capacity of all of these supplies aggregates 950 kw. Transmitter output amplifiers may be switched to more than one large rectifier; normally, several transmitters are served by one rectifier. A plug type switchboard permits any transmitter driver to be connected to any 3000 volt generator or rectifier. A system of locks and keys prevents interconnection of power sources. Cooling of tubes is effected by a water circulatory system equipped with two pumps (one a spare), each of 550 gallons per minute capacity; heat is transferred to the air through three large multi-fin cooling units backed by multi-vane blowers arranged so as to permit cooling the building in summer and heating it in winter. A continuously operating water conductivity measuring device is included in the cooling system.

Most of the transmitters consist of a 2 kw driver and an output power amplifier. Output amplifiers are of 10, 20 and 50 kw ratings. Each driver has three trays which roll out like file cabinet drawers, each tray containing a very low powered oscillator followed by some low powered amplifiers, permitting the setting up of three different frequencies. A selector switch connects the desired tray to the succeeding radio amplifier stages and to the amplifier power supply located within the unit. Other three position selector switches connect the proper pre-set tank


H.V. MOTOR GENERATOR CONTROL PANELS
TRANSMITTER CONTROL PANEL
10000 & 5000 VOLT D.C. SWITCHING UNITS AND MISCELLANEOUS CONTROL PANELS
SERGE TANK
WATER COOLING UNIT
CRANE
CABLE MANHOLE
SHAFT TO BASEMENT
TERMINAL SWITCH-BOARD
TEST TABLE
CONTROL CENTER
CONTROL LINE TERMINAL CABINET & FREQ. MONITORS
5000 V. MERCURY VAPOR TUBE REC'S 6 UNITS
MACHINE SHOP
STORE ROOM
BLOWER ROOM
HALL
MAIN ENTRANCE
STATION MANAGERS OFFICE
GENERAL OFFICE
LABORATORY
STORE ROOM FOR VACUUM TUBES AND MISC. SMALL SPARE PARTS.
TOILET AND WASHROOM
10000 V. MERCURY VAPOR TUBE REC'S. 6 UNITS
SPARE TRANSF.
INDUCTION VOLTAGE REGULATORS FOR 220 V. TRANSF. BANK.
SPARE LIGHTING TRANSF.
POWER SWITCHBOARD
LIGHTING TRANSF
OUTDOOR TRANSFORMERS FOR 10 000 VOLT REC'S
H.F. TRANSMITTER 20 UNITS
220 VOLT 3 ∅ TRANSF. BANK
440 VOLT 3 ∅ TRANSF. BANK
SPARE TRANSF.

FLOOR PLAN — MAIN FLOOR


SHAFT
HEATING PLANT
STORAGE BATTERY ROOM
6000 VOLT D.C. MOTOR GENERATOR SETS. 8 UNITS
SUMP & SUMP-PUMP
WATER CIRCULATING PUMPS
CABLE ROOM
STORAGE ROOM
110 VOLT D.C. MOTOR GENERATOR SETS FOR STATION CONTROL
500 CYCLE M.G. SETS.
CONTROL PANELS FOR SYN. MOTORS
5000 VOLT D.C. M.G. SETS 11 UNITS

FLOOR PLAN — BASEMENT

Fig. 3 B—Brentwood Transmitting Station. Floor Plan of Main Building.

circuit inductance for these stages, final tuning being done by resetting condensers. Thus shifting from one frequency to another can be accomplished very rapidly. Two transmitters used for the morning and evening transition frequencies have only one driver tray. Two other transmitters have three trays between them. The single 2 kw transmitter, used for the circuit to Washington, D. C., consists only of a driver unit equipped with three trays.

Oscillators are of a non-crystal control type, located in temperature controlled ovens; their power is supplied from a constant voltage regulating transformer, one of which is included in each driver. All oscillator tubes and their oven heaters run continuously and, therefore, are available for use instantaneously.

Motor generators, pumps, heating plant, a 60 cell storage battery and a large stockroom are in the basement. On the main floor are located offices, laboratory, machine shop, small stockrooms, water cooling apparatus and, in one large room, all switchboards, rectifiers, radio transmitters, monitoring equipment and control apparatus. This large room is made up of four building wings arranged in the form of a cross, at the center of which is the control desk and its associated apparatus racks. All transformers for power supply and for the six high voltage rectifiers are mounted on concrete slabs out of doors.

Electric power is purchased at 23,000 volts, passed through a substation of 600 KVA capacity located at the west boundary of the property and carried to the main building through two 2300 volt underground feeders, each 3000 feet long. At the building, transformer groups of $37\frac{1}{2}$, 150 and 450 KVA supply power for lighting purposes, 230 volt and 460 volt loads, respectively. Voltage regulators are associated with the 230 volt supply so that vacuum tube filaments can be energized from a source not subject to line voltage variations. Communication circuits are available from the south boundary of the property through a multi-conductor underground communication cable. Water is secured from a deep well.

The station is provided with twenty-seven directional high frequency antennas, oriented to points in Europe, West Indies, South America and Central America, as well as to Washington, D. C., New Orleans, Chicago, San Francisco and Los Angeles. Many of these antennas are provided with tuning networks, enabling them to be efficiently operated on any one of two or three frequencies without requiring any switching or physical changes other than connection to the desired transmitter. Several of the largest and most important antennas are provided with discriminating networks so that two transmitters, each working independently on a different frequency, may be operated simultaneously. Such operation has resulted in very marked economy in antenna costs, as well as in conservation of land area.

The special line impedance changing elements developed by the Company to accomplish these results, consist primarily of two types known, respectively, as re-entrants[2] and coupled sections.[3] The choice of type for a particular application is dictated by the conditions to be met, primarily frequencies used, the difference between them, and convenience in the physical disposition of the element at the point of application on the transmission line or its branches. In some cases, a single antenna will employ both types. The most flexible, however, is the coupled section. This device can be easily attached, has no electrical contact with the line, can be positioned and adjusted quickly, and produces no effect except for the frequency for which it is adjusted. Thus, by the use of this type of element on an existing antenna, line and antenna impedances can be matched for a new frequency without creating any mutual disturbances due to previously established set-ups for other frequencies operating on the same antenna. If re-entrant elements are used, they must be employed in conjugate relationship for multi-frequency operation.[2]

One mile and one mile and a half, respectively, from the main building are situated two small receiving stations, each equipped with two ultra-high frequency receivers, which are used to receive signals coming from New York and from the Southampton receiving station. One station is provided with 100 foot poles and the other

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[2] "High Frequency Transmission Line Networks," Andrew Alford, *Electrical Communication* January, 1939.

[3] "Coupled Networks in Radio Frequency Circuits," Andrew Alford, *Proceedings IRE* February, 1941, pp. 55–70.

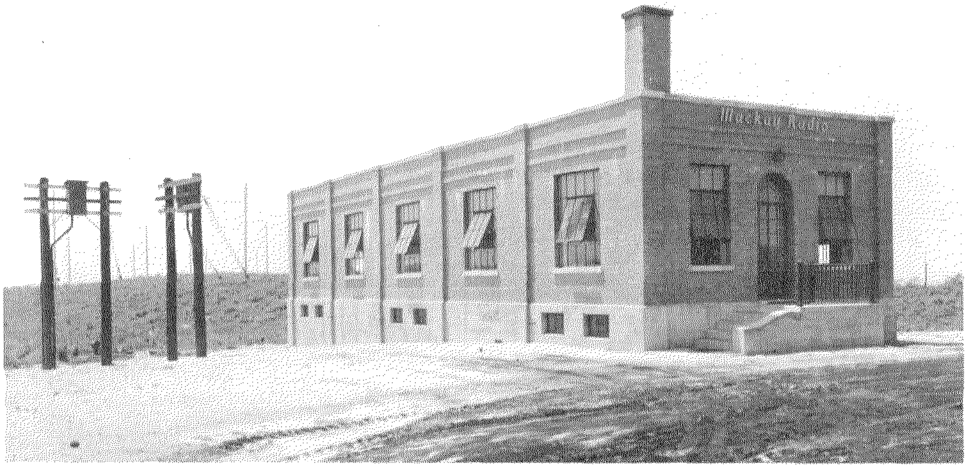


Fig. 4 A—Southampton Receiving Station, Point-to-Point Building.

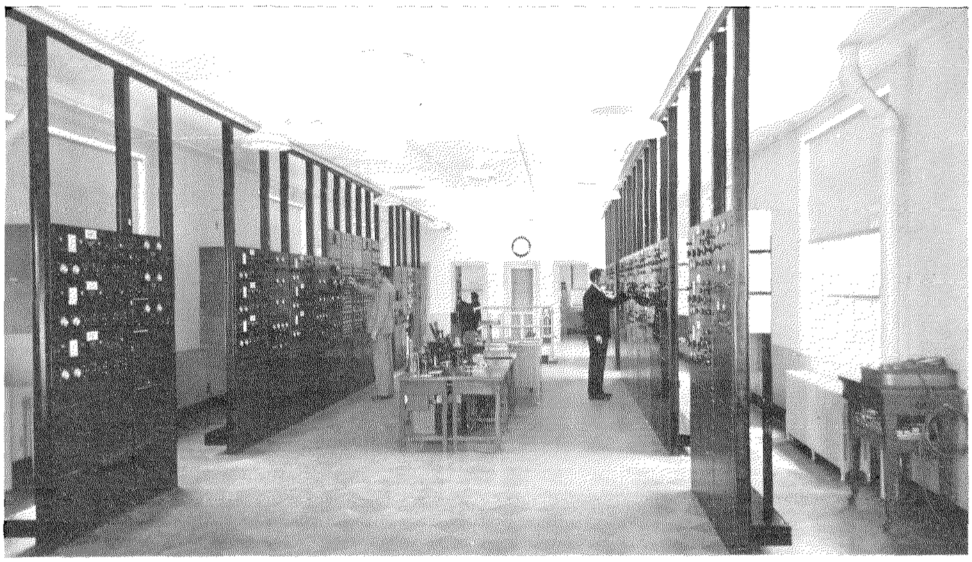


Fig. 4 B—Southampton Receiving Station, Point-to-Point Receiving Room.

with 200 foot guyed steel masts for supporting several ultra-high frequency antenna systems. Underground power and communication cables connect these points with the main building where the received signals are brought for connection to the terminal apparatus. The receivers are unattended and can be switched off and on from a control panel located at the operating center in the main building, at which place monitoring instruments are provided so that the operator in charge can check the operation of the receivers. This ultra-high frequency control system will be described in more detail hereinafter.

Southampton Receiving and Marine Service Control Station

Located north of the town of Southampton is the receiving station for both the point-to-point and shore-to-ship services. A one story and basement building houses the point-to-point equipment (Figs. 4-*A* and *B*). On the main floor are located the office, forty-seven radio receivers, a control board and a primary frequency standard including several associated receivers. In the basement are motor generators, storage batteries, charging equipment, heating plant, shop and ultra-high frequency audio terminal equipment.

Receiving apparatus is grouped in bays, each containing three receivers and one diversity keyer arranged as a unit for diversity operation. Switching facilities, however, provide complete flexibility, enabling the diversity groups to be made up of receivers and keyers regardless of location. Monitoring facilities permit listening in on any receiver or keyer output by means of an interlocking switch-key system. Two of the above mentioned receivers are associated with the ultra-high frequency remote control system.

The frequency standard, with its receivers, mixers and other devices, which enables any frequency between 15 kc and 165 mc to be picked up and accurately measured, is located in a separate room.

Connected with this building are fifteen high frequency antennas, including three for the frequency standard set-up. Most are of a directional aperiodic type; several receivers operating independently on different frequencies can receive signals from one antenna. For diversity reception, antennas are arranged in groups of three, being directed toward Europe, South America and the Pacific Coast of the U. S. A. Outdoor type transformers of a unique design, suitable for a 5 to 22 mc range, match open wire transmission lines from antennas to twisted conductor pairs having a characteristic impedance of about 125 ohms and low loss insulation. These twisted lines enter the building underground and reach receivers via a patching jack panel.

In another building of two stories and basement is located the Marine Receiving and Operating Department. On the main floor two low, two intermediate and eight high frequency receivers are mounted on a table arranged in the shape of a "U," accessible to operators seated within the "U." These operators have the control of the ship-to-shore transmitters at the Amagansett station. Message traffic for this Operating Department is transferred to and from the Company's Marine Bureau at 67 Broad Street, New York, N. Y., over a telegraph circuit.

Low and intermediate frequencies in the bands allocated internationally for ship services are picked up by rotatable loop antennas located on the top floor of the building in conjunction with outdoor antennas supported above the building, permitting unidirectional reception from any direction. This arrangement aids in reducing interference from undesired signals and discriminates considerably against static which comes predominantly from a southwesterly direction.

Seven high frequency antennas are available for reception from ships, some of which are directed toward the North Atlantic ship lanes. Switching facilities available at each high frequency operating position allow selection of directive or non-directive antennas.

In the basement of this building are storage batteries, charging equipment, heating plant and storeroom.

Other small buildings provide for two ultra-high frequency transmitters, material storage and an emergency, gas engine driven power plant. The ultra-high frequency transmitting antenna is supported on a 200 foot guyed steel mast. The gas engine generating plant is capable of supplying all power requirements on the property. Power and communication conductors between buildings and to the utility companies are underground.

Amagansett Transmitting Station

This station (Fig. 5) is situated on a narrow neck of land between Long Island Sound and the Atlantic Ocean, located in a salt water marsh which floods at high tide. The one story building contains one 10 kw intermediate frequency transmitter, two 15 kw low frequency transmitters and three 10 kw high frequency transmitters. One 100 kw 10,000 volt and two 25 kw 10,000 volt rectifiers supply anode power for output ampli-

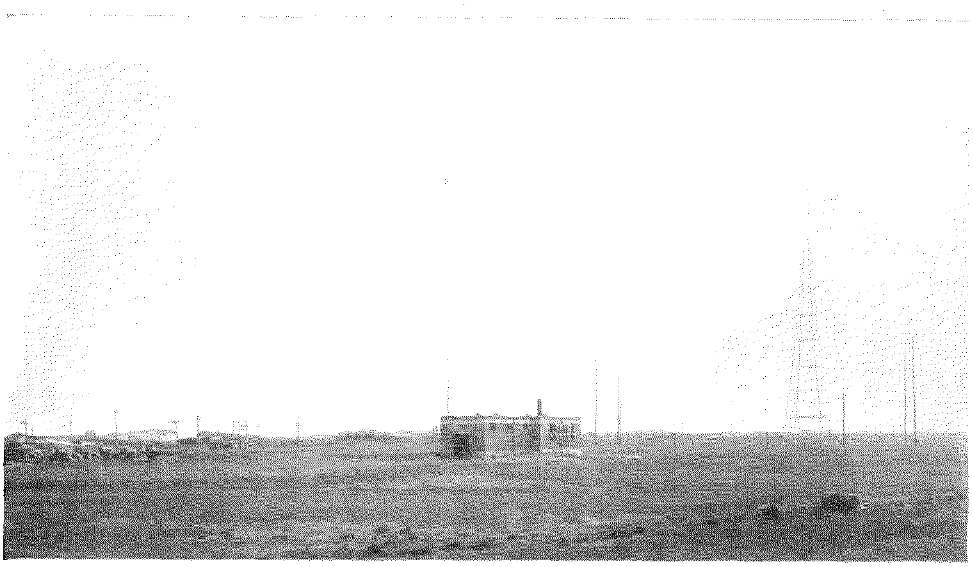


Fig. 5—Amagansett Transmitting Station.

fiers. Two 5,000 volt and two 3,000 volt rectifiers provide power for tubes in other amplifier stages. A flexible high voltage switching system permits connection of any combination of loads to any power supply. The central water circulating and cooling system for water cooled tubes is of the type described above for the Brentwood station, but of smaller capacity.

The high frequency transmitters each consist of one 2 kw, three tray driver, associated with two output amplifiers. This permits rapid frequency change inasmuch as the idle output amplifier can be pre-tuned at leisure for the frequency next to be employed.

Of the nine high frequency antennas, some are directional, others non-directional types. The operators at the Southampton control station select the antenna desired through a selective switching system, which also serves to shift the intermediate frequency transmitter from calling to working waves, or vice versa, at the will of the operator in control. The directional antennas are oriented to serve the North Atlantic ship lanes. The non-directional antennas radiate vertically polarized waves; some are stacked and fed with power to create radiation predominantly in the horizontal plane but tilted upwards in all directions at an angle favorable to the frequency and distance involved.

Two 300 foot non-guyed steel towers support one low frequency and one intermediate frequency antenna. Both are provided with means for melting sleet by circulating through their conductors large currents obtained from the 60 cycle power supply. A two frequency network arranged for 109 and 120 kc permits feeding the single low frequency antenna by both low frequency transmitters simultaneously.

Power is supplied from the Power Company's nearby substation at 4000 volts through two underground feeders. Communication lines also enter via an underground cable.

New York Central Operating Department

The sending and receiving of messages for the point-to-point services is performed in the Central Operating Department on the fifth floor of the International Telephone Building at 67 Broad Street, New York, N. Y. Messages arrive and leave via pneumatic tubes and belts which connect with the Commercial Cable Company, All America Cables and Radio, Inc. (all on the same

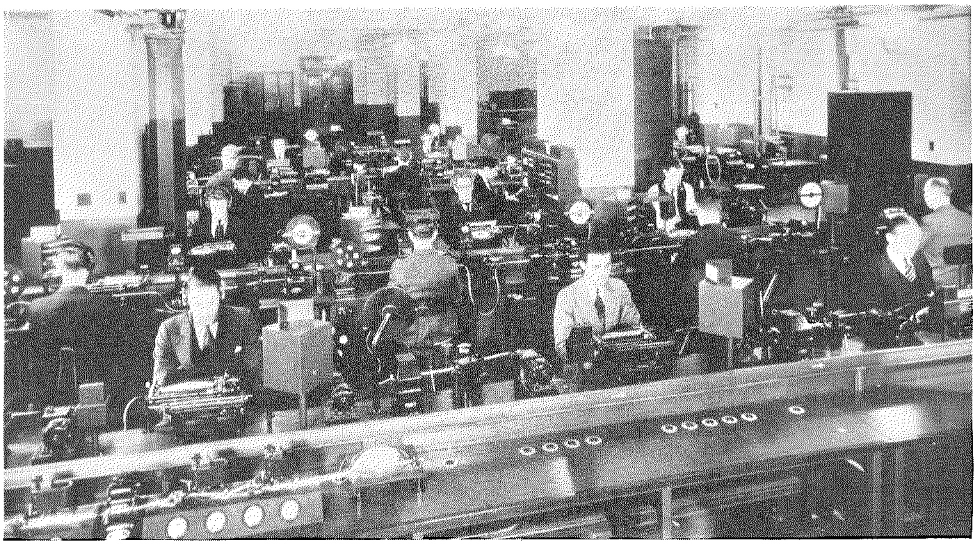


Fig. 6 A—Portion of Mackay Radio Operating Department, International Telephone Building, 67 Broad Street, New York, N. Y.

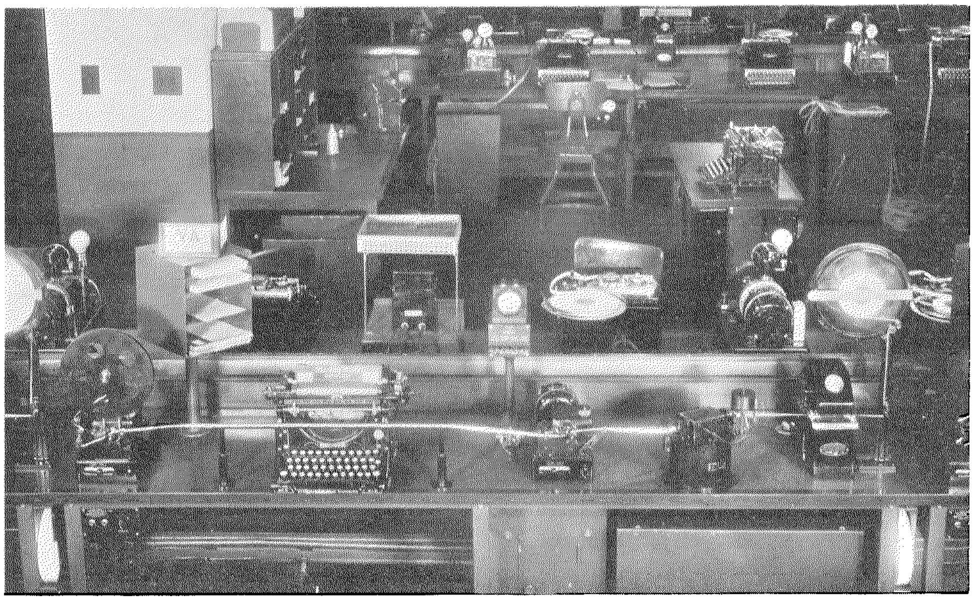


Fig. 6 B—View of Automatic Transmitting and Receiving Equipment, New York Operating Department, 67 Broad Street, New York, N. Y.

floor) and the Postal Telegraph Company at 20 Broad Street. Tie lines, printer circuits and special telephone lines provide connections to many important customers.

The facilities directly associated with the radio circuits comprise groups of transmitting and receiving operating positions (Figs. 6, *A* and *B*). Each transmitting position is equipped with a keyboard perforator by means of which the sending operator spells out the message onto a paper tape in the form of perforations. An automatic transmitter translates the tape perforated message into the electrical dot and dash impulses which make up the telegraph code and which automatically key the radio transmitter at the Brentwood station. Each receiving position is equipped with a tape ink recorder which scribes a zigzag line, corresponding to the telegraph signals being received, on a moving paper tape. Paper reels, draw-off motors, and a tape guide in front of a typewriter provide the means that enable the receiving operator to transcribe the message contained on the tape to a message blank by typewriter. A time stamp automatically marks this tape at frequent intervals for providing an accurate record of time of receipt of messages. One or more transmitting positions are operated as a group with one or more receiving positions to terminate a duplex radio circuit permitting the flow of traffic in both directions simultaneously. As normally operated, corresponding transmitting and receiving position tables are located back to back with the operators sitting at them facing each other. Each receiving position has a hand key enabling the operator to break in on the transmitting position of the duplex circuit. When this hand key is depressed the transmitting circuit, which is being controlled by the automatic transmitter, is shifted to the hand key and a red warning light is illuminated on the transmitting position. A delay type relay restores the normal connections a short time after cessation of hand key manipulation. This arrangement allows the receiving operator to ask for repeats or give instructions to the other end of the circuit without delay.

The automatic equipment is capable of transmitting and receiving at speeds up to 200 words per minute, which is far beyond the capacity of one operator on each side of the duplex circuit. For circuits involving traffic volume beyond the handling capacity of one man per side, positions are ganged up into groups of two or three. A three position group would have three sending and three receiving positions manned by six operators. The incoming signal is connected to all three receiving position recorders in sequence under the control of the operators by means of key switches provided with indicator lights. When an operator has finished transcribing the message on the tape before him, he waits for the end of the message being recorded and transcribed by one of the other operators. At this moment he moves his switch key which stops the writing of the recorder of this other operator and transfers the signal to his own recorder. At the next appropriate interval between messages the third operator will take over the recording in the same manner. Thus the received signals are passed around among three operators, who between them can keep up with the rate at which messages are arriving.

A similar arrangement for the three transmitting tables enables three operators to prepare punched tape at a rate sufficient to keep up with the speed of the automatic transmitter.

A special group of operating positions is associated with a radio concentrator for handling lightly loaded circuits that do not justify the continuous attention of individual operators specifically assigned to them. The concentrator permits the connection of a busy circuit to an unoccupied operator.

A monitor recorder, capable of making twenty four traces on both sides of a wide paper tape, records all outgoing radio signals. This record has been found invaluable from an operating standpoint in facilitating the identification of errors, equipment difficulties, etc.

The outgoing signals from the operating tables control tone keyers which are associated with the ultra-high frequency control system, the radio transmitters for which are on the roof of the building. Signals from the receiving station arrive as audio tone currents, which are converted by amplifier-rectifiers into direct current suitable for energizing the recorders.

The office is equipped with a total of 19 transmitting and receiving positions, and 6 combination transmitting and receiving one-man positions associated with the concentrator.

A printer operating group terminates leased wires connecting with Philadelphia, Camden, Detroit and Boston.

New York Marine Bureau and Harbor Marine Station

Located also on the fifth floor at 67 Broad Street is the Marine Bureau (Fig. 7) which includes a telephone PBX board, telegraph connections to the Southampton Marine Operating Department, pneumatic tube connections to other carriers, and the receivers and transmitter controls for the small harbor marine radio station previously mentioned. Two unattended transmitters of one kw output each, located on the 35th floor of the building, provide service on the intermediate and low frequency bands used in the mobile service.

Ultra-High Frequency Control System

All transmitters at the Brentwood station are remotely controlled from the New York Operating Department through an ultra-high frequency radio transmitting and receiving link. Two ultra-high frequency transmitters operating in the band 156 to 162 mc are located in a small house on the roof of the building in New York with a power output of approximately 50 watts each. A control panel with monitoring instruments in the operating room provides remote starting and stopping of this apparatus which otherwise is unattended. One of the transmitters is a spare.

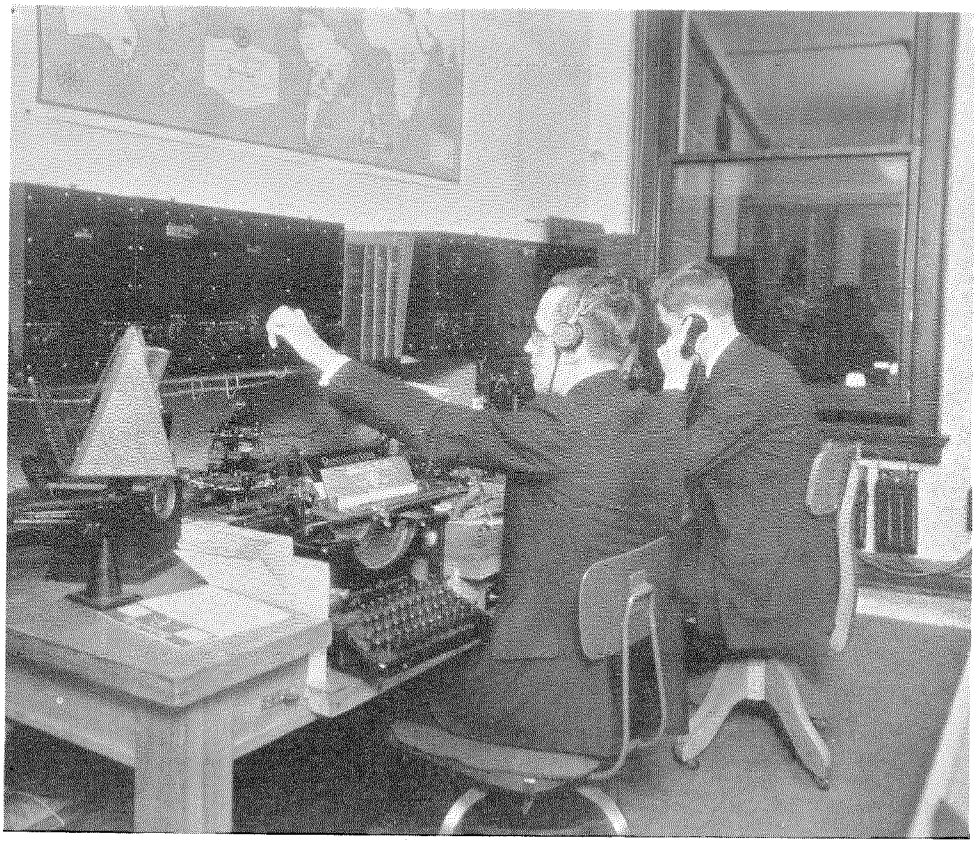


Fig. 7—New York Marine Harbor Station, Operating Positions.

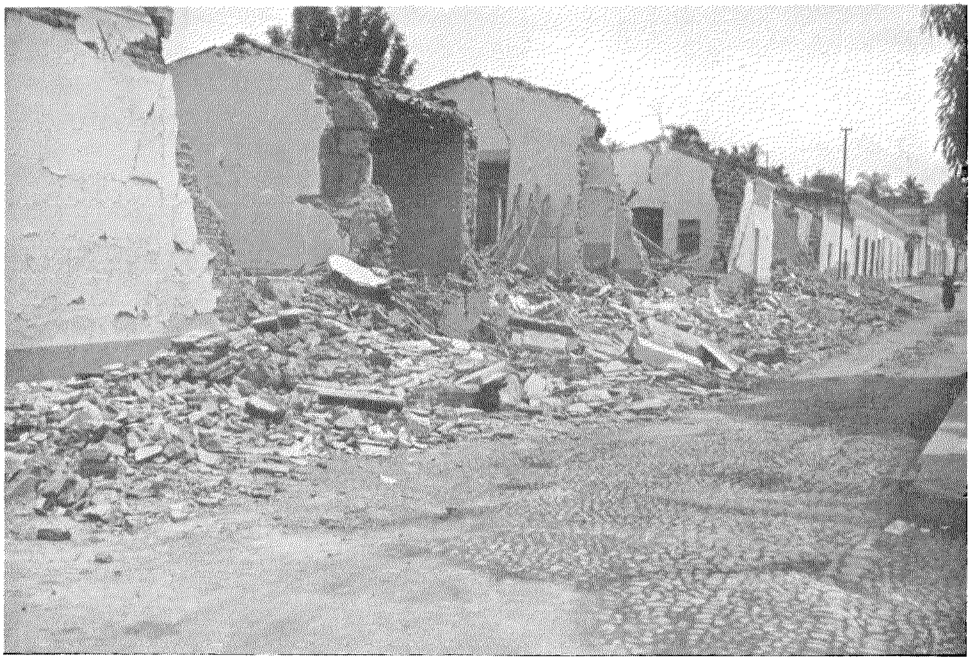
The transmitter is arranged for modulation by 23 frequencies ranging from 200 to 12,000 cycles. These audio frequencies represent the individual telegraph control channels, each frequency being keyed by one of the circuit, operating table transmitting positions in the operating room. At Brentwood a receiver removes the carrier frequency, and the resulting low frequency currents derived from the receiver output are passed through filters and then converted into direct current. These direct current impulses are then individually used for keying the radio transmitters. Seven of these low frequency keying channels are for moderate speed operation, the pass bandwidth of the filters being approximately 62½ cycles. The other 16 channels are for high speed keying with pass bandwidths of the order of 300 cycles.

A similar system operates between Brentwood and Southampton, and is being used for carrying six channels of received signals from Southampton to Brentwood, where they are repeated and passed over leased wire circuits to the New York Operating Department. This system is being expanded and, at the present time, similar facilities are being provided between Southampton and Amagansett to enable transmitters in the Amagansett station to be remotely controlled from the Marine Operating Department at Southampton.

The system between New York and Brentwood has been in successful operation for several years and that between Brentwood and Southampton for the past two years. It is of interest to note that this ultra-high frequency system was of considerable value at the time of the 1938 hurricane, during which period there was considerable damage done to the wire line plant on Long Island. Temporary installation of ultra-high frequency facilities between Southampton and Amagansett at that time made possible the resumption of service a number of days prior to the restoration of the wire line system normally used.

The Company has carried on considerable development work on ultra-high frequency antenna systems, and is successfully using array types with gains of the order of 9 to 12 db, designed to minimize the effects of sleet. During a severe sleet storm in the spring of 1940, one of these array type antennas operated successfully for several days while heavily coated with ice.

Neither the New York-Brentwood, nor the Brentwood-Southampton antennas are in a line of sight. The propagation path in each case crosses several groups of Long Island hills.



A Street in Colima After Partial Clearance.

Railroad between Guadalajara and Colima Buried Five Meters as a Result of Landslides.

Earthquake—Colima, Mexico

By M. MEHL

General Plant Superintendent, Compañía Telefónica y Telegráfica Mexicana

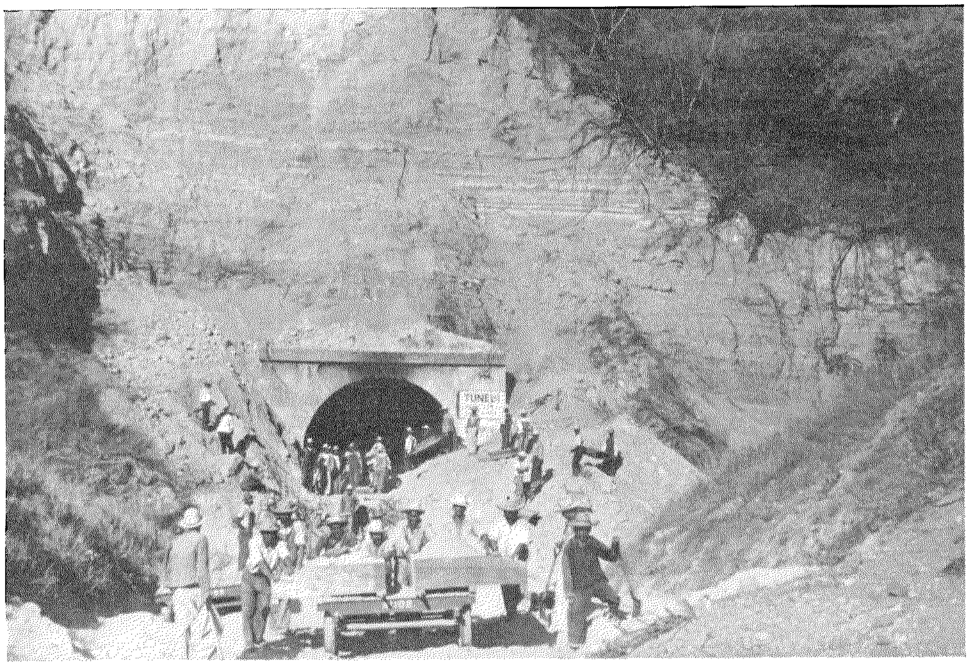
Editor's Note

This account of recent earthquake destruction of outside plant in a sparsely settled section of southwestern Mexico far from headquarters, and measures taken to restore the telephone service is based on the author's field notes. To reach Colima as rapidly as possible he traveled by automobile, mule back and on foot over regions where roads had disappeared, vast dust-laden torrid deserts and dried up lakes, sleeping under freight cars and suffering from weariness, blistered feet, hunger and thirst. The record provides another instance of the high determination of the communications worker to maintain communications notwithstanding difficulties imposed by man or nature.

ON April 15th, 1941, at approximately 1 p.m. a severe earthquake shook the southwestern part of Mexico. While considered equally severe in Mexico City both as to intensity and duration, the resulting destruction in the Capital was relatively unimportant due to the character of the subsoil.

Routine checking within Mexico City showed that none of the Mexican Telephone and Telegraph Company plant had suffered damage. It was soon found, however, that all the Company circuits between Guadalajara and Colima, a pole line distance of 259 km, were out of commission. The telegraph service also was interrupted and the railroad between the two towns was destroyed. The afternoon papers reported that Colima and Tuxpan, with populations of 24,000 and 1,500, respectively, had suffered severely along with small neighboring villages.

In view of the seriousness of the situation, the author immediately left for Colima via Guadalajara, Sayula, and Ciudad Guzmán, arriving there after three days of travel by automobile, mule back and some 50 kilometers on foot. Normally, the train trip from Mexico City



Clearing a Tunnel Head After Complete Obstruction by Landslides.

to Colima, a distance of about 450 miles, takes 20 hours.

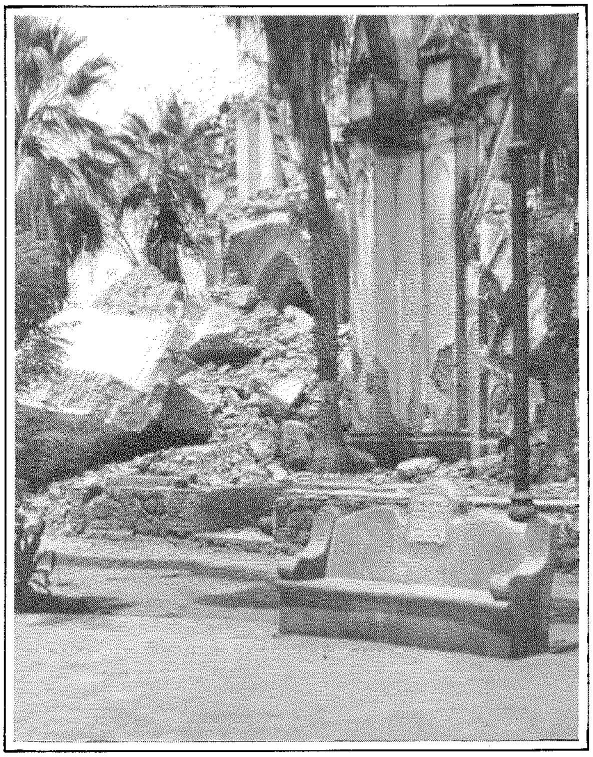
Reaching Colima after dark and traversing the ruins of the city with the aid of a flash light, the author found the telephone office only slightly damaged. But the general aspect of the city was deplorable: the houses in general being of adobe were in ruins, and the streets were completely blocked with debris. Martial law had been proclaimed and the inhabitants were living in the public squares and gardens. Light and water services were unavailable. Telephone toll circuits were severed in numerous places between Colima and Guadalajara, due mainly to landslides. Work to re-establish service was immediately started, but progress was retarded due to set-backs occasioned by landslides and blasting by railroad repairmen. On Sunday, April 20th, five days after the catastrophe, a telephone call was completed from Colima, via Guadalajara, to Mexico City.

News of re-establishment of telephone service and consequent resumption of contact with the outside world occasioned great excitement. Long queues were formed by people desirous of getting in touch with families in neighboring towns.

The local outside plant was found to be practically totally covered by wreckage. It was mainly of special block construction consisting of small iron poles attached to the roofs of houses; cable messengers and cables were suspended from the poles. When the houses collapsed, the cables parted and were almost a total loss. Drop loops also were damaged but were repaired and re-used.

Local service to the Government, Police Force and hospitals was almost immediately restored by running drop loops from temporarily erected poles.

The question arose as to whether Colima should be rebuilt on its present site or moved elsewhere. The residents, in general, preferred the present location, but decision was deferred pending arrival of the President of the Republic who was expected as soon as railroad service could be resumed. On learning that the majority of the people wished Colima restored on its present site, the President acceded to their views.



Colima Cathedral in Ruins.

Prior to returning to Mexico City, the author visited the towns of Tuxpan and Zapotiltic, both of which had been completely destroyed. These towns are relatively small and the resulting loss of life and property fortunately was not great. It is claimed that the tremors in this section were more intense than those of the San Francisco earthquake of 1906.

Prior to the earthquake the Company had 248 telephones in Colima. By June 23d, 187 telephones had been restored to service and 36 installations were being deferred pending reconstruction of buildings. The balance of 25 telephones was lost as a result of subscribers moving from the city or discontinuing their service.

Selenium Rectifier Characteristics, Applications† and Design Factors

By CAROLE A. CLARKE, S.B. in E.E.

International Telephone & Radio Manufacturing Corporation, New York, N. Y.

Starting with a brief review of the general functions of a rectifier, this article describes the Selenium Rectifier (including static and dynamic characteristics), gives examples of applications in the power and communications fields and an indication of data required for specific rectifier designs. Subsequent articles will be devoted to: (a) novel applications of Selenium Rectifiers and (b) methods of rectifier design.

The Selenium Rectifier, due to its reliability, flexibility and economic advantages, is finding wide application in practically all branches of industry. The decision, made in 1938, to commence manufacture in New York was particularly fortunate because of the practically unlimited supply of selenium in North America.

THE importance of efficient, economical rectifiers results from the almost universal acceptance of alternating current for generation and distribution of power, coupled with increasing demands for direct current obtained from an a-c source. For a-c rectification, consequently, motor generators, rotary converters, vacuum tubes, liquid and vibrator types of rectifiers, as well as metallic-junction or dry plate rectifiers such as the Selenium Rectifier, have found wide application.

The Selenium Rectifier is an International Telephone and Telegraph associated company development; it was introduced in Europe in essentially its present form in 1928. (Latest available estimates of its acceptance abroad indicate that 88% of metallic-junction rectifiers in use are of the selenium type.) Application in the U.S.A. commenced in 1938 when the International Telephone and Radio Manufacturing Corporation,* New York, commenced its manufacture. An indication of its wide range of application may be obtained from Fig. 1, showing an oil-immersed, 6 volt, 1,000 ampere, three phase, full wave, center tap connected rectifier employing the largest size selenium plates available and, for comparison, held between the thumb and forefinger, a rectifier stack made up of four of the smallest size plates in regular production in a single phase, full wave, bridge connected rectifier for an output of 12 volts, 150 milliamperes.

Basic Considerations

A rectifier is defined as a device possessing the ability to pass electric current freely in one direction while offering much greater or almost total resistance to the passage of electric current in the reverse direction. Thus crystal detectors may be classified as rectifiers, though their power capacity must be measured in microwatts, as compared with kilowatts handled by metallic-junction rectifiers of much greater effective rectifying surface. The ideal rectifier, if such existed, would offer zero resistance to the flow of current in the forward direction and infinite resistance to the flow of current in the reverse or blocking direction. Lacking ideal rectifiers, selection must necessarily be made from available types with due consideration of important factors such as first cost, useful life, annual charges, size, weight and efficiency.

Rectifier Plate Construction

I. T. & T. Selenium Rectifiers differ in their construction from other rectifiers of the metallic-junction type, principally in the electrodes themselves and in their semi-conducting layers. In these rectifiers the semi-conducting layer is derived from the metallic element selenium and consists of the thinnest practical coating (approximately 0.05 mm) of high purity selenium applied to one side of a processed steel plate, which serves as the back electrode. The selenium coating is itself covered with an alloy, serving as a low resistance front electrode and providing uniform distribution of current throughout the active material. Further heat treatments create a layer between the front electrode alloy and the selenium, resulting in increased difference in resistance for currents flowing in the forward and reverse directions. Current flows readily from the back electrode to the front electrode, i.e., in the steel to selenium direction, but practically not at all from selenium to steel. Each plate thus constitutes a valve or half wave rectifier; full wave rectification is obtained with two or more half wave elements in one of the conventional single or three phase circuits.

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† Article is based on material used by the author in presentations of the subject before various Sections of the American Institute of Electrical Engineers, The Institute of Radio Engineers and the International Municipal Signal Association, as well as in a series of two colloquia for the Electrical Engineering Department of the Massachusetts Institute of Technology.

* Formerly the International Telephone Development Co. Inc.

Electrical and Physical Advantages

Fig. 2 illustrates the construction of a Selenium Rectifier plate in cross section, but does not represent the relative thicknesses of the various layers. Besides serving as a back electrode the sturdy steel plate provides rigid support, giving the strength necessary to withstand physical shocks, vibration and stresses. The steel also provides the necessary surface for convection cooling under all normal operations. Rectification takes place entirely within this one-piece sturdy plate.

The plates range from $\frac{3}{4}$ inch to $4\frac{3}{8}$ inches in diameter, seven sizes in all; they may be assembled in compact stacks consisting of the plates, contact discs, spacers, insulators, terminals and a center stud with or without mounting brackets. The flexible, petal-shaped contact discs are of brass and make contact with a considerable area of the rectifier plate. Contact terminals are brought out from the plates in various arrangements for series or parallel con-

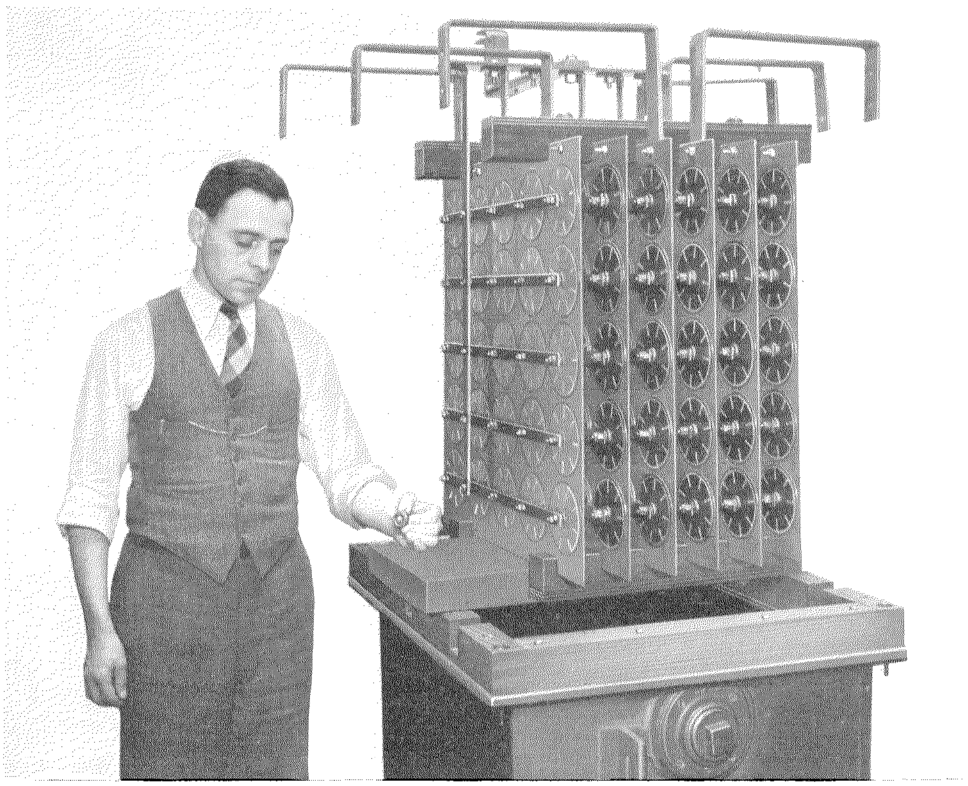


Fig. 1—Oil Immersed 6 v, 1000 amp., 3 Phase, Full Wave, Center Tap Connected Rectifier (Shown Out of Its Oil Tank Below) and 12 v, 150 ma, Single Phase, Full Wave, Bridge Connected Unit.

nection of the plates, as required. Since each plate is a complete rectifying element, pressure is not required beyond that necessary to establish electrical contact and the rectifier therefore is not critical to pressure changes. The electrical parts of the stack assemblies are completely insulated from the stud and mounting brackets. If necessary, high potential tests of individual stacks may be applied up to 3,000 volts a-c, thus exceeding A. I. E. E. requirements. Parts of a rectifier stack are shown in Fig. 3.

Unlike thermionic rectifiers which depend upon heat to produce electron emission, the d-c output from a Selenium Rectifier is available immediately upon application of the alternating voltage, avoiding the delay of a heating-up period. The materials of Selenium Rectifiers do not deteriorate during normal operation. Since Selenium Rectifiers are electronic devices their life is not limited by chemical action or thermal elements which may wear out. They have in fact been in continuous service over a period of many years without showing any signs of deterioration and hence are assumed to possess unlimited life. There are no moving parts or materials requiring maintenance or renewal.

The rectifier stack is essentially an assembly of compact, light metal parts ruggedly built to outlast associated equipment. An assembled I. T. & T. Selenium Rectifier stack is shown in Fig. 4. It will be noted that the rectifiers are designed for mounting with the assembly stud in a horizontal position so that normal air convection provides for all but unusual cooling requirements.

With proper protection of metal parts Selenium Rectifiers can be used under highly unfavorable atmospheric conditions and the normal separation of electrical parts permits their use at high altitudes. For most applications the output is sufficiently stable as a function of time and temperature not to require compensation, and the device lends itself readily to use in circuits with manual or automatic adjustment.

High permissible reverse voltages and high permissible working temperatures make it possible to obtain high power output with a small quantity of plates. These factors permit light, small rectifier stacks. Relatively large unobstructed cooling surfaces permit the use of small diameter plates. Simplicity of design, light hardware and compactness of the units, added to flexibility in mechanical and electrical arrangements, permit easy installation of Selenium Rectifiers and their adaptation to unusual requirements.

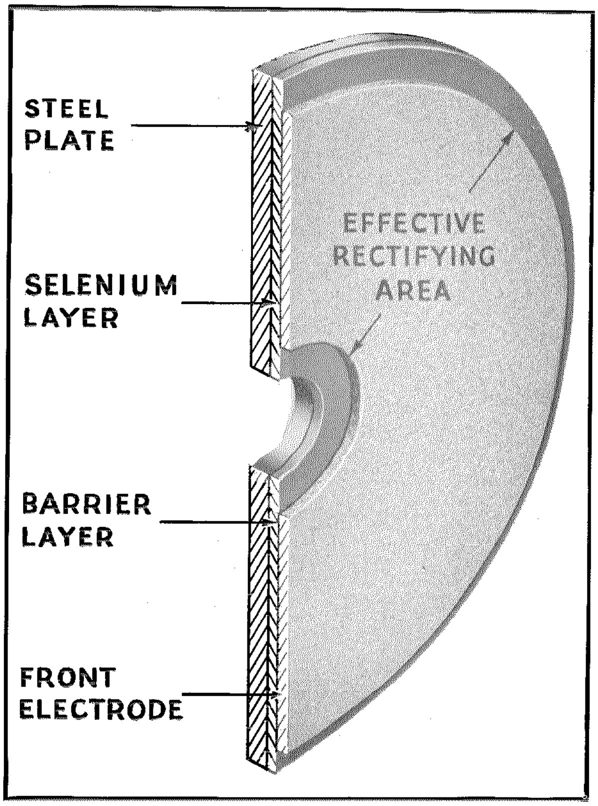


Fig. 2—Cross-Section of Selenium Rectifier Plate.

Rectification occurs over a wide range of applied frequencies.

Static Current Characteristics

Static forward and reverse characteristics of a Selenium Rectifier are shown in Fig. 5. Attention is directed to the fact that the reverse current is plotted to two scales because of its low values. The ordinate for the dotted reverse current curve is only 1/100th of that used for the solid line. The curves represent the static characteristics of a Selenium Rectifier plate of one square centimeter effective area. The characteristic always passes through the origin with the current increasing rapidly for low values of forward voltage and finally becoming almost linear. Due to its very low resistance in the forward direction and

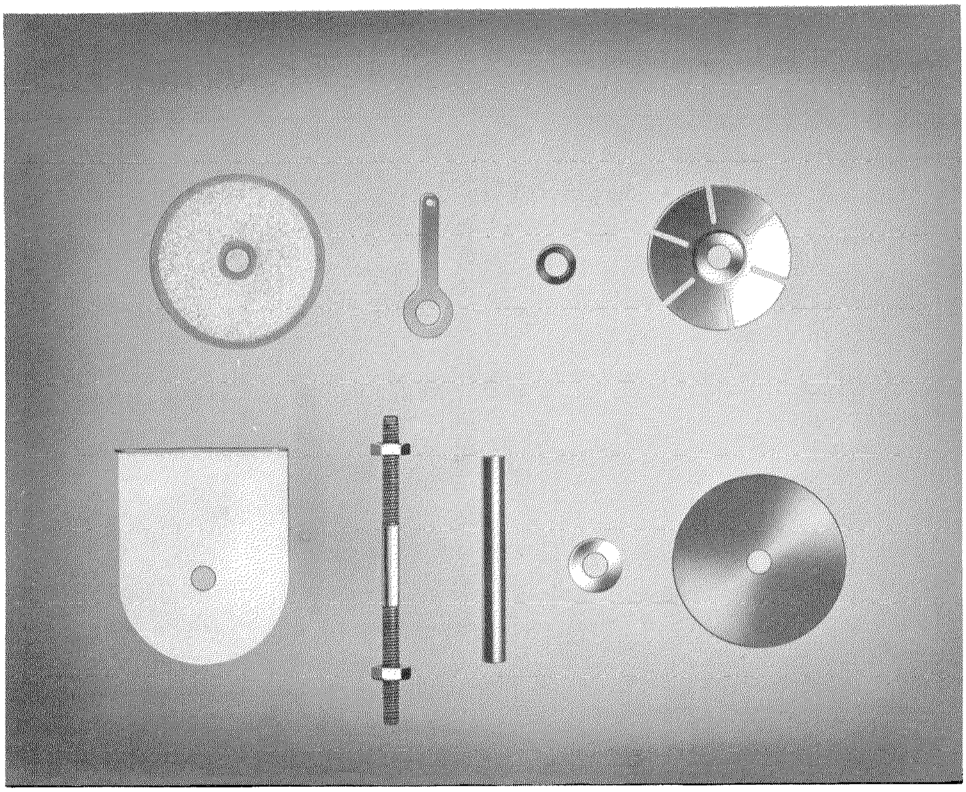


Fig. 3—Components of a Rectifier Stack.

Top Row, Left to Right: Selenium Rectifier Plate; Terminal Lug; Pressure Limiting Washer; Petal-Shaped Contact Disc.

Bottom Row, Left to Right: Mounting Bracket; Center Stud; Insulating Sleeve; Spacing Washer; End Insulator.

high resistance in the reverse or blocking direction, a high rectification ratio with good regulation is attained.

Applications of Static Characteristic

The negligible reverse current or "back leak" shown as a solid line in Fig. 5 finds a valuable practical application in battery charging rectifiers through the elimination of equipment for disconnecting the battery from the rectifier when the rectifier is turned off or the a-c supply is interrupted. This characteristic also makes possible the use of one or more single plates connected as a valve between an automobile or airplane generator and its associated battery in place of the usual cutout relay. When the generator voltage exceeds that of the battery, current flows through the valve to charge the battery, but when the engine driving the generator slows down or stops, the high back resistance of the valve prevents battery discharge through the generator.

A further example of valve action is presented by the connection of a rectifier plate of appropriate size across an inductance in a d-c circuit for quenching the arc across a disconnect switch or contactor. The valve is so connected that it does not pass the d-c impressed on the inductance, but when the d-c circuit is broken, the inductance discharges through the low resistance path of the valve with practically no increase in the voltage across the inductance. Resistance may be inserted in the valve circuit to adjust the rate of current decay.

Translation of the static characteristic curve into resistance values (Fig. 6) shows that the single plate valve has a negative resistance characteristic in the forward direction closely approximating an exponential curve. The forward resistance increases sharply from a low value at the normal operating current to a maximum as the voltage approaches zero. If two valves are paralleled with their conducting directions in opposition, the device becomes a variable resistance shunt for an applied a-c and has proved effective as a volume limiter or acoustic shock reducer in telephone circuits subject to severe inductive interference. The double valve unit is connected across the telephone receiver or other portion of the circuit to be protected. For normal speech currents of low voltages, the shunting effect of the valve unit is negligible. For high voltages due to inductive "kicks" the valve resistance drops instantaneously to low values, thus effectively limiting the voltage across the telephone apparatus; consequently, the sound output level is not injurious to the ear of the telephone listener.

Dynamic Current Characteristics

The dynamic forward and reverse current characteristics of Selenium Rectifiers may be graphically observed and studied with the aid of an oscillograph. Fig. 7 shows the wiring diagram employed for such studies and the accompanying description indicates the technical procedure followed. Figures 8 and 9, respectively, are reproductions of oscillograms of the dynamic forward and reverse current characteristics of a single Selenium Rectifier plate.

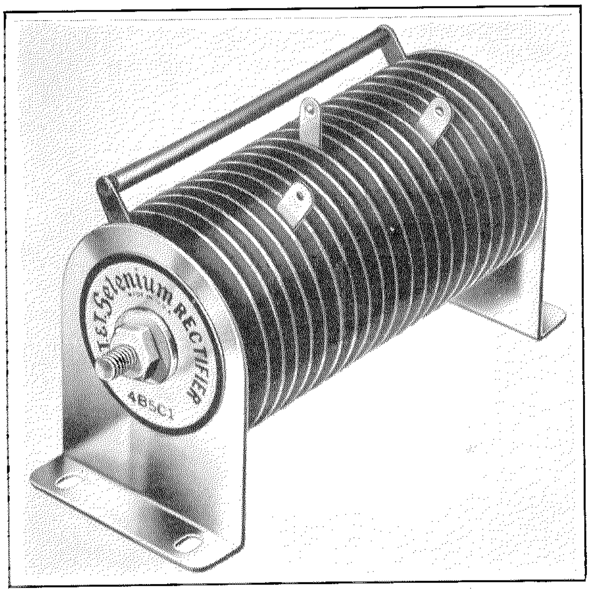


Fig. 4—I. T. & T. Selenium Rectifier.

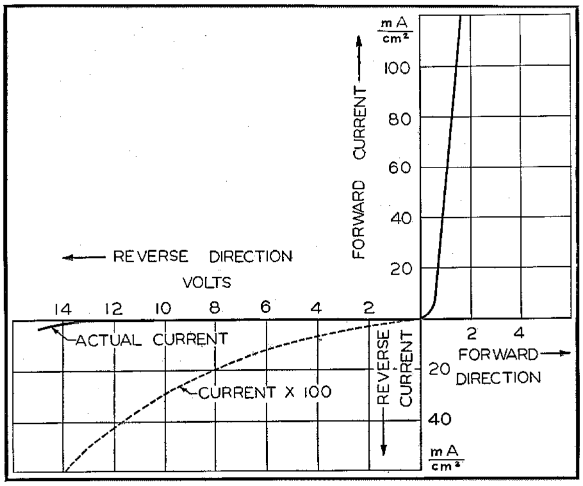


Fig. 5—Typical Static Forward and Reverse Current Characteristics. Reverse Characteristic Shown to 2 Scales.

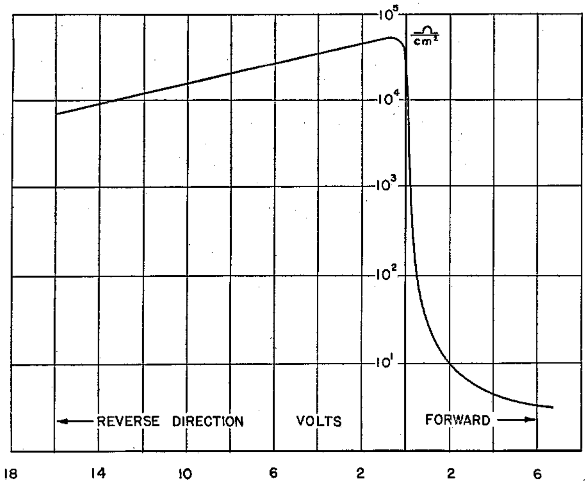


Fig. 6—Typical Static Resistance—Voltage Curve of a Selenium Rectifier Plate Having an Effective Surface Area of 1 cm².

Unlike most electrical apparatus, the forward resistance characteristic of the Selenium Rectifier as a function of plate temperature has a negative slope. The resistance decreases rapidly

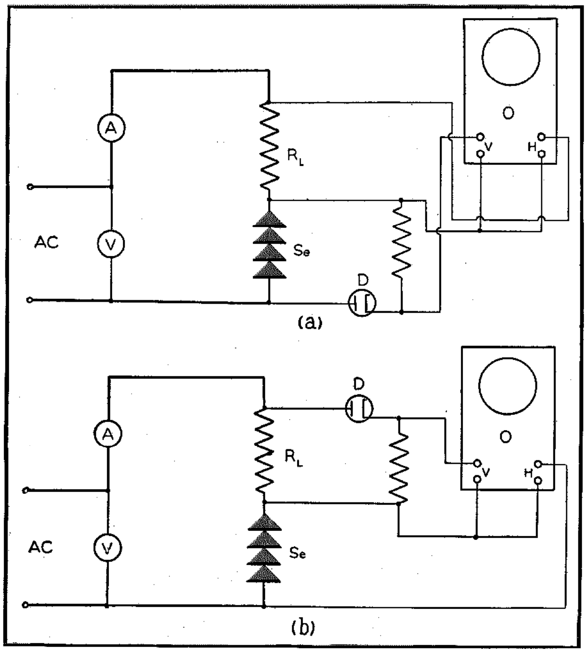


Fig. 7—Connections for Obtaining Dynamic Characteristics of Selenium Rectifiers: (a) Forward Characteristic; (b) Reverse Characteristic.

Rectifier, Se, is connected in series with an alternating current supply, AC, and pure resistance, R_L. Since the overall characteristic involves large changes in voltage and current values depending on whether the Rectifier, Se, is blocking or passing current, the circuits above give means of recording the passing and blocking characteristics separately.

For the forward characteristic, the oscillograph, *O*, is connected as in (a). The voltage across the resistance, R_L, is so connected that the horizontal deflection of the oscillograph is proportional to the valve current. The high voltage peaks of the valve voltage in the reverse direction are suppressed by the diode, *D*, and this voltage is then connected to the oscillograph so that the vertical deflection is proportional to valve voltage.

For the blocking characteristic the oscillograph is connected as in diagram (b). The high blocking voltage of *Se* is now connected for producing horizontal deflection. The voltage across R_L, due to reverse current, is impressed on the vertical deflectors through the diode *D*. The vertical deflection hence is proportional to the reverse current.

By connecting several valves in series, the average characteristic of the several valves is then obtained with little distortion due to the diode *D*.

as the temperature increases from very low values, but only slightly in the usual range of working temperatures. The upper curve of Fig. 10 shows the relative drop in voltage across a plate, or its decrease in resistance, with temperature rise, for a constant full load current density. It should be noted that the total rectifier forward resistance is only about 10% of the total load circuit resistance; hence, the change in the rectifier voltage drop is a quite negligible percentage of the value of the output voltage. Furthermore, rectifiers which must operate at unusually low temperatures generally also must be designed for high temperature operation and their rated current or current density decreased in accordance with Fig. 11 which is fully discussed later. Thus the relative change in internal voltage drop compared to a normally loaded rectifier is decreased; the lower curve of Fig. 10 shows this change for a current density corresponding to one-tenth full load. In actual service, the negative temperature coefficient of the rectifier resistance is largely counter-balanced by the positive temperature coefficients of transformer, choke and load resistances.

Variation in reverse resistance at 2 and 18 volts, respectively, is indicated in Fig. 12 for the same range of plate temperatures. Actual resistance values are different but, in order to show the form of the two graphs on one illustration, both the 2 volt and 18 volt reverse currents are assumed as unity for a rectifier temperature of 25° C. It is obviously of fundamental importance that the reverse resistance be and remain high even under extreme temperature conditions.

Applications of Dynamic Characteristics

The relatively small change in reverse current with temperature contributes not only to the high efficiency of the rectifier and extends its usefulness over a wide range of temperatures, but it also is of value in protecting a rectifier load including an e.m.f. such as a battery from inadvertent discharge. In railway signal use, for example, groups of batteries and their associated trickle chargers, such as the type shown in Fig. 13, are housed along the right of way, usually in black-painted, weather-resistant cabinets with restricted ventilation. While this arrangement serves to maintain the ambient temperature inside the cabinet well above the outside temperature in cold weather, the inside temperature may rise to excessively high values during sunny summer days. Under such conditions it is a prime requisite that the rectifier reverse resistance be maintained as high as possible.

Power Factor

From a dynamic standpoint, the negative resistance characteristic of the Selenium Rectifier tends to produce a forward current wave shape in which the successive half wave pulses deviate very slightly from true sine wave form because of the minute changes in forward resistance which follow the cyclic change in input voltage. Although current and voltage pulses are in phase in the rectified output, the measured wattage does not exactly equal the product of the measured effective current and voltage due to the harmonic content of the output. Thus the measured rectifier power factor differs slightly from unity and is found to be of the order of 97% to 99% in single phase, depending on conditions of use.

Stability of Output

Both the forward and reverse resistances of the Selenium Rectifier increase with age, causing a higher internal drop and consequent decrease in output voltage, which is offset to some extent by the smaller loss in the reverse direction (Figs. 14 and 15). Aging usually takes place within the first 10,000 hours of full rated continuous operation. In intermittent or light load operation this period is longer; in extreme cases, 40,000 to 50,000 hours. A new rectifier will show no change in output for a considerable length of time, and,

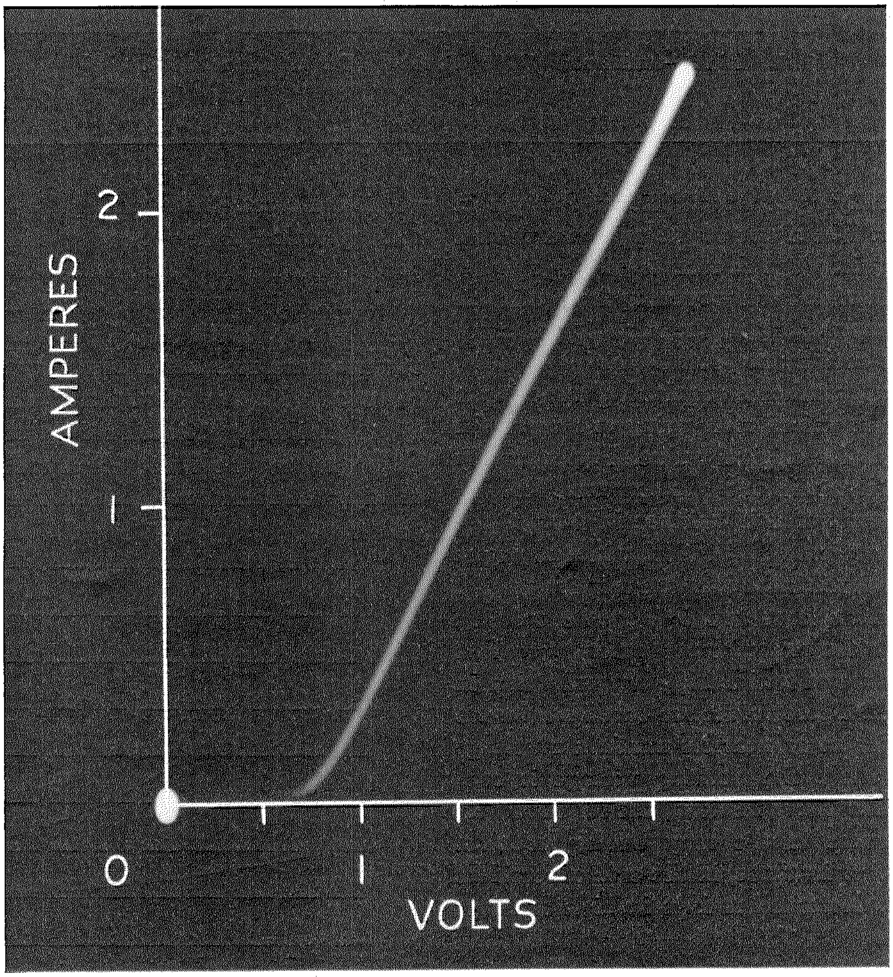


Fig. 8—Oscillogram of Dynamic Forward Current Characteristic.

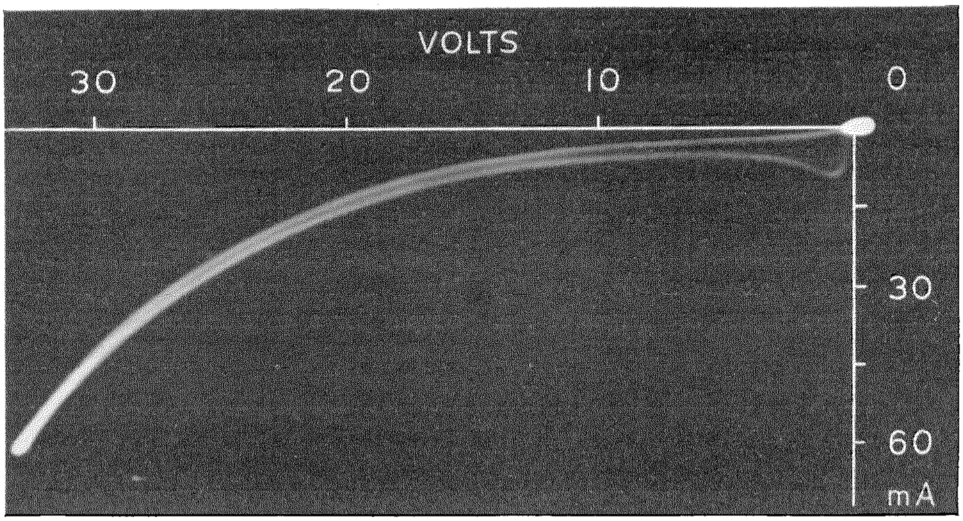


Fig. 9—Oscillogram of Dynamic Reverse Current Characteristic.

once it has fully aged, no additional changes in output occur. The shape of the aging curve and the time required are functions of the specific conditions of use and cannot readily be predicted. Experience shows that in the majority of cases aging can be entirely neglected.

If full compensation is required, the a-c input voltage may be raised after aging to restore the d-c output to its original value. For normally spaced rectifiers without supplemental cooling fins, the amount of this increase in a-c voltage usually does not exceed 5%. With wide spacing of plates or cooling fins the increase may be as high as 10%, and at least two 5% taps should be provided on the transformer secondary. Fan cooled units may require 15% compensation in extreme cases. These values are based on the use of the rectifier at or near its maximum voltage per plate. Where the working voltage is considerably under the maximum, the required percentage increase in a-c may be higher than indicated as, for instance, in the case of rectifiers operating at decreased ratings in high ambient temperatures.

Cooling and Temperature Considerations

Selenium Rectifiers are designed with adequate self-cooling facilities utilizing normal air convection. Forced draft cooling may be employed and operation under oil is practicable for both protection of metal parts and cooling.

Since the forward resistance of a Selenium Rectifier is not zero (Fig. 5), the forward flow of current generates heat. The very small flow of current in the reverse direction also adds to the heat generated within the plate. The alloy employed as the front electrode has a lower melting temperature than the selenium; the

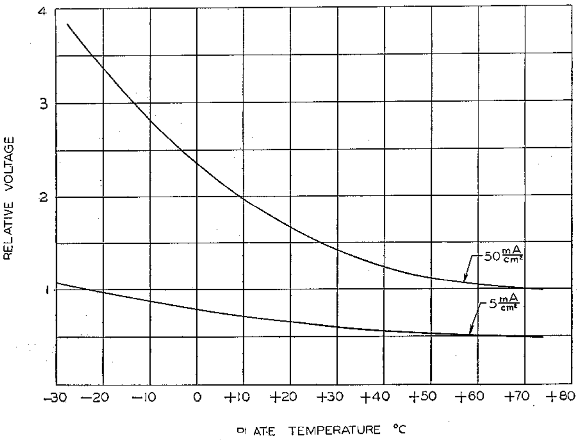


Fig. 10—Forward Voltage Change with Temperature for Full Load and One-Tenth Full Load.

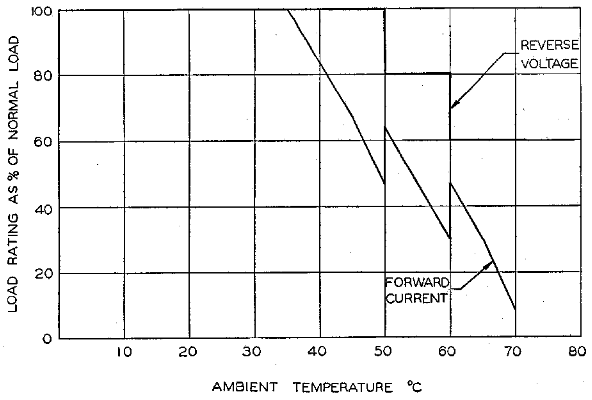


Fig. 11—Load Rating vs. Ambient Temperature.

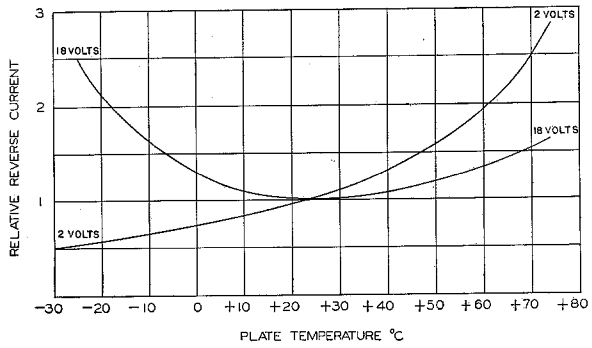


Fig. 12—Reverse Current vs. Plate Temperature for Normal Voltage and a Fraction of Normal Voltage.

melting temperature of the alloy, therefore, sets the *absolute maximum* temperature at which the rectifier plates may be operated. Considerations of safety require that the temperature rating of selenium plates be established with an ample margin of safety below this limiting maximum temperature.

Ambient Temperature Range

Like most electrical power equipment, Selenium Rectifiers are designed for a temperature rise of 40° C. above an ambient temperature of 35° C. (95° F.) for continuous operation. Their maximum safe plate temperature of 75° C. (167° F.), for aged plates, affords an ample safety factor for the metallic coatings of the plate and at the same time permits the use of the rectifier over wide ranges of ambient temperature.

Extremely low ambient temperatures of the order of −40° C. (−40° F.), or lower, are favorable to I. T. & T. Selenium Rectifier operation since they offer a larger margin between temperature of the surrounding air and the maximum safe operating plate temperature.

When the rectifier must operate in ambient temperatures above 35° C., the rectifier power output must be decreased or the size of the rectifier increased so that the sum of internal forward and reverse losses will not raise the plate temperature beyond a maximum of 75° C. Since the reverse losses are a function of the applied a-c voltage and the forward losses vary with load current, both voltage and current ratings are decreased as the ambient temperature increases towards 75° C.

The percentage of decrease in ratings necessary when the ambient temperature exceeds 35° C. is represented in Fig. 11. It will be noted that at 50° C. and 60° C. either of the corresponding pairs of ratings may be used, the choice being determined by economic considerations or the physical dimensions of the respective designs.

The high temperature at which the Selenium Rectifier can be operated permits many unusual applications, including outdoor use and condi-

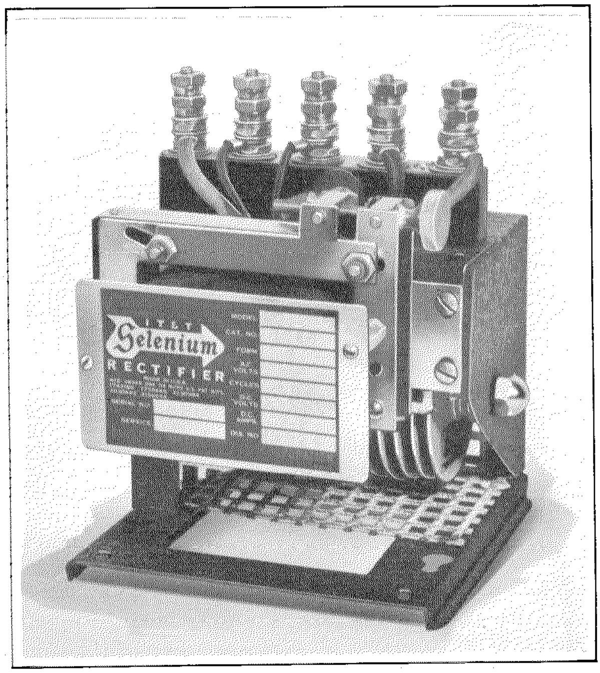


Fig. 13—Battery Charging Rectifier with Case Cut Away to Show the Selenium Rectifier. (Courtesy of Fansteel Metallurgical Corporation.)

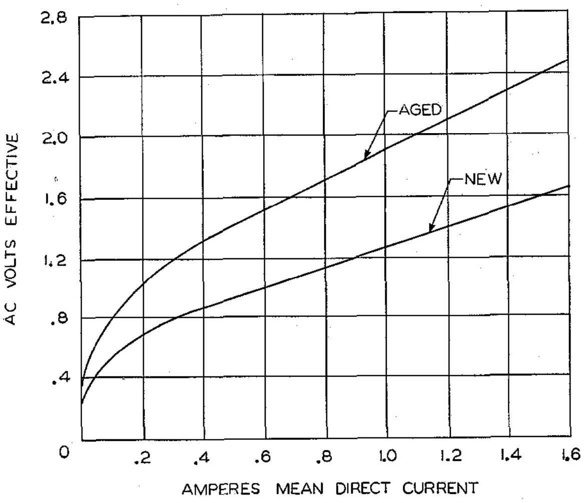


Fig. 14—Typical Forward Voltage Drop and Direct Current Output Curves for a New and an Aged Rectifier.

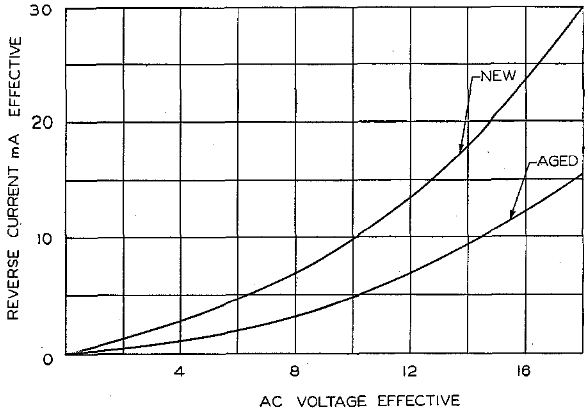


Fig. 15—Typical Reverse Current—Voltage Curves for a New and an Aged Rectifier.

tions involving restricted ventilation in close association with equipment generating heat.

Applications at High and Low Ambient Temperatures

An interesting example of extreme temperature operation is afforded by the application of the Selenium Rectifier to the coaxial cable amplifier, Fig. 16. The amplifier is housed in a sealed, non-ventilated metal case which also includes thermionic tubes, transformers and resistors contributing to the internal temperature rise. Some of these amplifiers are located in manholes, others atop poles where direct rays from the sun add to the internal heat. The rectifier is used for anode supply for the tubes and was designed for continuous operation in ambient temperatures of −40° C. to +68° C. As compared with a mercury vapor rectifier tube for this application the Selenium Rectifier, in addition to unlimited life, has the advantage that it operates instantly at −40° C. ambient temperature whereas mercury would solidify.

Fig. 17 pictures a vacuum tube plate supply rectifier for use in an unattended radio transmitter station. The unit is designed to operate in an ambient temperature range of −40° C. to +60° C. With an input of about 3,000 volts single phase a-c, this rectifier supplies 2,300 volts, 180 milliamperes at the output of the associated filter.

Cathodic Protection

An unusual outdoor application of the Selenium Rectifier for unattended use is in forced drainage or counter-electrolytic cathodic protection of underground pipe lines, telephone cables, water tanks or other equipment subject to electrolysis.

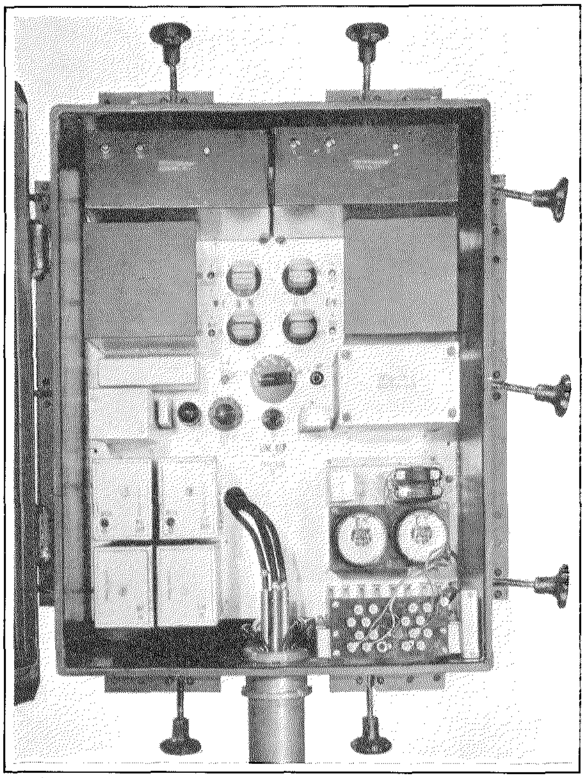


Fig. 16—Coaxial Cable Amplifier. (Courtesy of Bell System Technical Journal.)

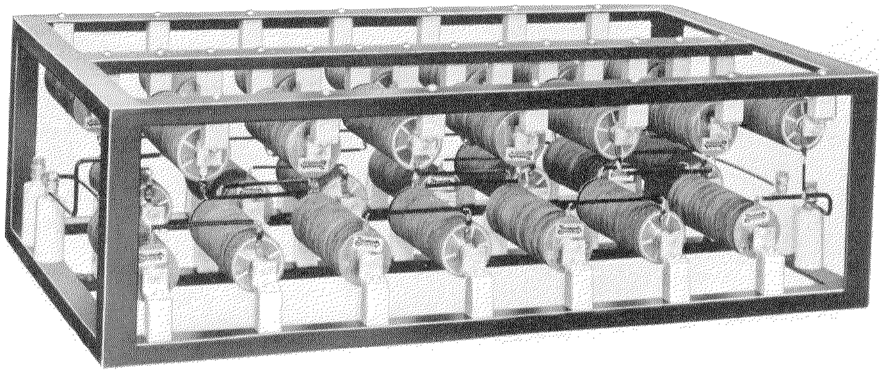


Fig. 17—Anode Supply Rectifier for Use in Radio Transmitter. Single Phase Bridge Circuit for Output from its Associated Filter of 2,300 Volts, 180 Milliamperes, in Ambient Temperatures of − 40°C. to + 60°C.

The usual scheme applied to pipe lines is to more than neutralize the e.m.f. generated by the pipe as a primary cell by forcing a larger current between pipe and ground in the direction opposite to the locally generated current. The rectifiers are located along the pipe line at selected intervals; they are mounted on poles which also carry a telephone line, one side of which may serve as an a-c power conductor with the pipe as a return. A typical cathodic protection rectifier is shown in Fig. 18.

Reverse Voltage Limitations

The blocking resistance in the reverse direction decreases with increasing voltage up to the point of breakdown of the barrier layer. Under normal operating conditions the permissible maximum reverse voltage which may be impressed on a single plate is, in most cases, 18 volts r.m.s. for a sinusoidal wave shape or about 25.5 volts peak. When an applied voltage greater than this value is necessary, more than one rectifier plate must be used in a series connection.

Operating Limitations

From the foregoing it is evident that the amount of reverse voltage which may be impressed upon an I. T. & T. Selenium Rectifier is limited only by the breakdown voltage in the reverse direction. The current output, similarly, is limited only by the maximum permissible plate temperature produced by the combined internal losses of the rectifier plates, largely forward current loss. A current density of about 50 milliamperes per square centimeter is permissible continuously in the forward direction, corresponding to about one volt drop per series plate. For most applications the important design factor is insuring ample margins for operating within the permissible plate temperature limit of +75° C. (determined by power output) down to any low temperature value where the limitation is solely one of voltage regulation.

Reverse Voltage Blocking Characteristic Changes

A peculiar characteristic of the Selenium Rectifier is that the longer the rectifier is operated at a low reverse voltage the less it will withstand the *sudden* application of higher reverse voltages, thus requiring that the change to higher voltages be gradual. This blocking characteristic is changeable over protracted periods of time and must be considered when the rectifier is used alternately

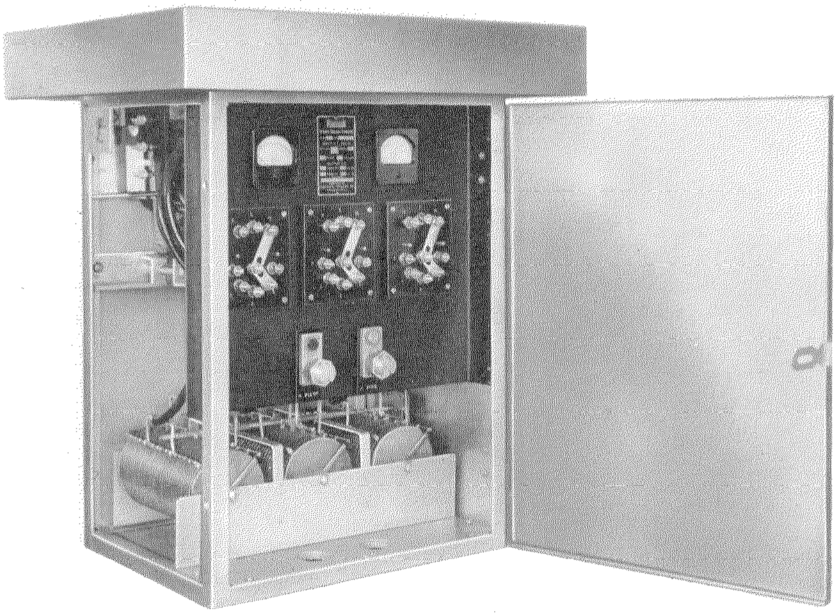


Fig. 18—Cathodic Protection Rectifier for Pipe Line Service Housed in Drip-Proof Weather Resistant Cabinet for Pole Mounting. Output 14 Volts, 100 Amperes. (Courtesy of Electrical Facilities, Inc.)

at different voltages. The decrease in reverse resistance takes place very slowly after the voltage is reduced, becoming noticeable only after several days. When the voltage is increased, however, the reverse resistance increases very rapidly, becoming noticeable within a few minutes. When this characteristic is observed in action with an oscillograph the restoration of reverse resistance becomes dramatically visible as it progresses from second to second. Rectifiers which have been used at very low reverse voltage for some time and are then connected to a much higher voltage will, for a few minutes, show an abnormally high leakage current, which thereafter assumes normal value.

This characteristic is also noticeable after a rectifier has been lying idle for a considerable period. When restored to service, the a-c potential should be started at a low voltage and increased gradually to the required value. Occasionally crackling sounds occur as the electrostatic stresses reach an equilibrium but this phenomenon can be entirely disregarded as it has no effect on the life or performance of the rectifier.

Heavy Permissible Overloads

Since the permissible current output of the Selenium Rectifier depends entirely upon its ultimate temperature, no theoretical limit can be placed on its current handling capacity. A unit which is initially cool can supply many times its normal continuous current during the time required to bring it to its limiting safe plate temperature. At this point the load must be decreased to a value which does not exceed the normal continuous rating. The relation between load and operating time for a temperature rise of 40° C. is shown in Fig. 19, which applies to cases where there is a sufficient interval between successive load applications to permit the rectifier to cool

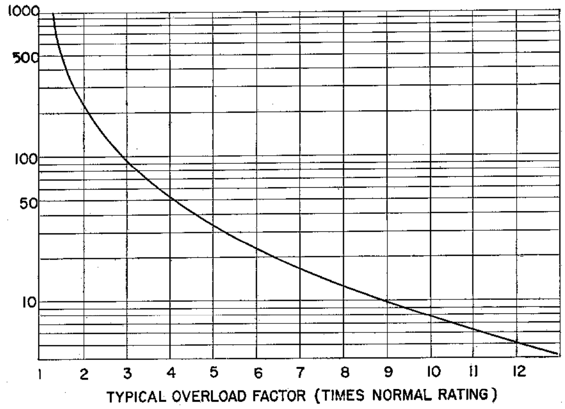


Fig. 19—Typical Short Period Overload Capacity of a Selenium Rectifier. (The curve assumes a half-hour period of idleness between operations to allow the rectifier to cool.)

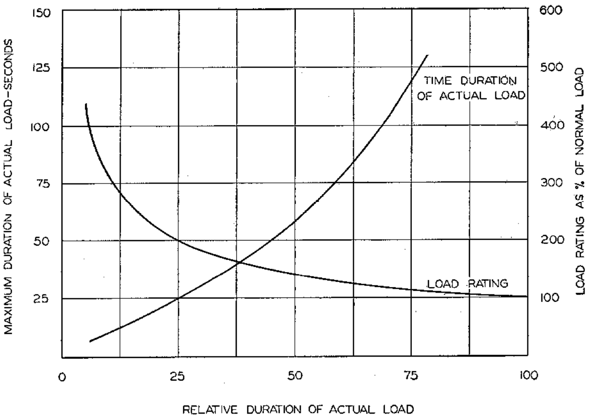


Fig. 20—Overload and Operating Time for Intermittent Operation.

to its initial temperature of 35° C. If the rectifier is started at a lower temperature, a somewhat longer application of overload is permissible. If the starting temperature is above 35° C., the overload must be decreased in accordance with Fig. 11.

Fig. 20 shows similar curves for intermittent operation when the intervening idle periods are too short for cooling to the surrounding temperature. One curve shows the relation between percentage operating time and permissible overload; and the other, the corresponding maximum operating time in seconds. It should be noted that intermittent use does not permit application of voltages above the normal continuous ratings.

While there is no limit to the current which can be supplied by a Selenium Rectifier for short periods, it must be remembered that the rectifier is a resistance device so that the higher its current output the higher also will be its internal voltage drop. Where the actual operating time is short, the rectifier temperature may not rise appreciably above its surrounding temperature. Fig. 21 shows a typical heating curve for a convection cooled Selenium Rectifier assembled with normally spaced plates without cooling fins and operated at its normal full load rating. The shape of this curve can be changed by altering plate spacing and cooling facilities. Choice of a suitable rectifier design for extremely short period operation is therefore determined by the permissible voltage regulation or at least by the minimum operating voltage required at the load.

It is usually possible to compute the temperature rise and so design rectifiers for intermittent operation provided the duty cycle can be defined. In cases where the cycle is not recurrent or is too complex to permit ready description, laboratory checks under actual operating conditions may be required, the ultimate plate temperature of the rectifier and its output voltage under load being the determining factors.

Applications of Overload Characteristic

In practice, rectifiers are frequently used for intermittent service in elevator operation, alarm equipment and many control circuit applications. For such uses the rectifier has a distinct advantage in that its standby losses are small compared to rotating machines, and it is not injured by sudden high overloads which would rapidly destroy thermionic devices dependent upon a heated element to produce an electron stream.

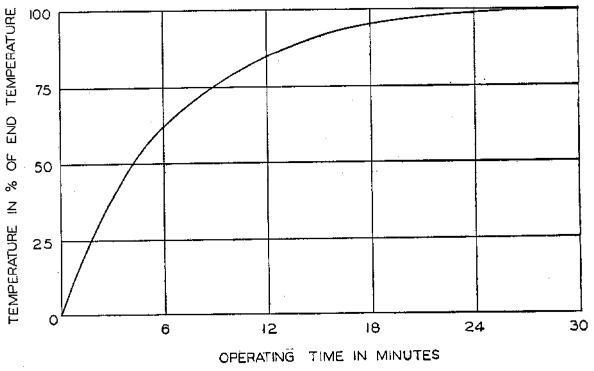


Fig. 21—Typical Temperature Rise vs. Time Curve.

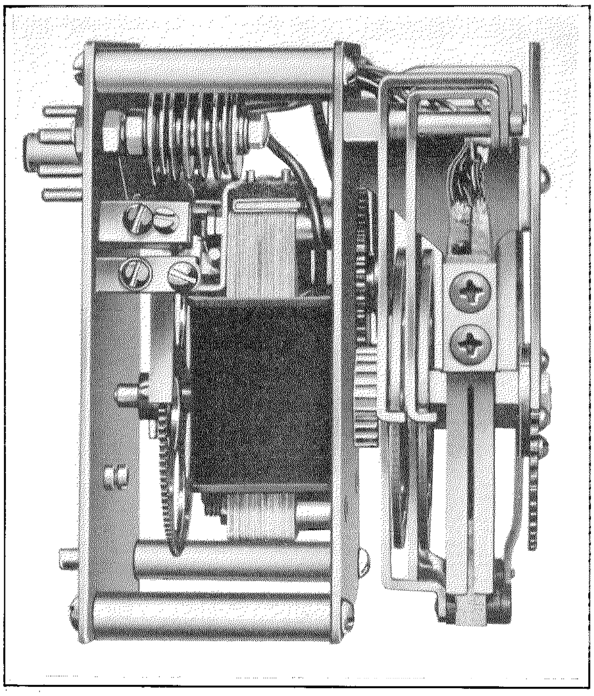


Fig. 22—Code Transmitter for Operating an Alarm Circuit. (*Courtesy of The Holtzer-Cabot Electric Company.*)

Program clock and bell services, such as required for schools, represent an interesting form of intermittent operation. Here the rectifier must operate a number of clocks which are stepped ahead each minute by the application of the rectifier output for perhaps one second per operation as determined by a master clock. At other intervals, which may or may not coincide with the clock operation, vibrating bells may be operated for various lengths of time and single stroke bells operated one or more times. A code transmitter for operating an alarm circuit is shown in Fig. 22.

Plate Types and Ratings

Selenium Rectifier plates, because of adequate cooling surface, inherently do not require cooling fins. However, such fins are often used to extend the current capacity of the largest size of plate as well as to obtain current values intermediate between the normal ratings of smaller plates. While the relationship of plate spacing to diameter is chosen for optimum cooling at normal current rating, an increase in rating can also be obtained by increasing the spacing between plates. The determination of plate size, and whether or not cooling fins or wider spacing or both should be used, are governed by the economics of each specific case. Forced ventilation, rather than the addition of fins, may also be economical under certain conditions.

Table I lists basic types of Selenium Rectifiers and their ratings. The normal full load output current in amperes is given for each type on the basis of one plate (or several in series) in each branch of the listed rectifier circuits. Output currents can be increased by the connection of plates in parallel. Plate reverse voltages, outside diameters and d-c valve ratings are included in the table. The forward currents permissible for d-c valve use are higher than the equivalent half wave rating for a-c operation because there is no simultaneous heating due to reverse current. As noted for rectifiers used at low reverse potentials, it is not recommended that valves be operated for long periods with forward current only. Occasional applications of reverse potential should

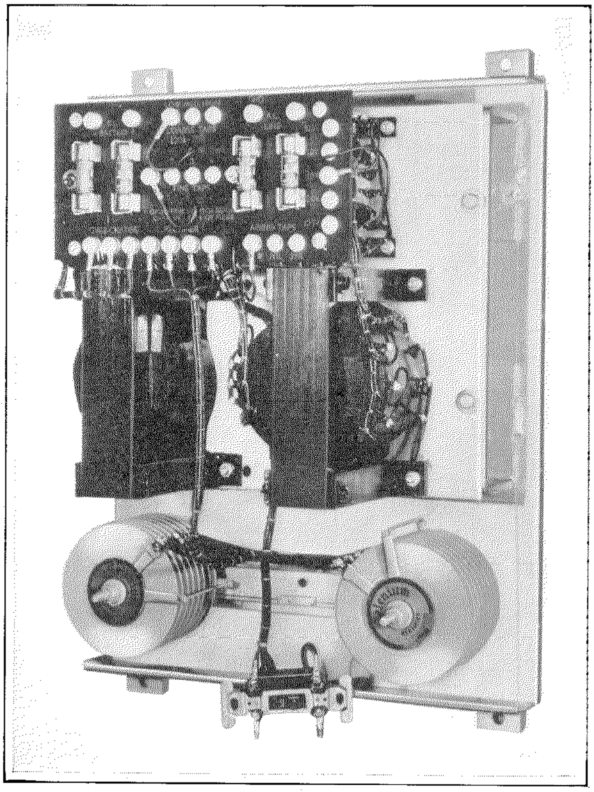


Fig. 23—Saturable Core Reactor Type Regulating Rectifier for Telephone Central Office Power Supply. (*Courtesy of The North Electric Manufacturing Company.*)

Type No.	Diameter Inches	Max. R. M. S. A. C. Volts reverse per plate	*Maximum continuous D.C. amperes for one plate per arm at 35° C. ambient, inductive or resistive load						Maximum Continuous D.C. rating as valve at 35° C. ambient		Maximum No. of plates per stack	Using Plate No.
			Single Phase			Three Phase						
			Half Wave	Bridge	Center Tap	Half Wave	Bridge	Center Tap	Amperes	Blocking Voltage		
1	¾	18	.040	.075	.075	.100	.110	.130	.06	15	36	1
2	1	18	.075	.150	.150	.200	.225	.270	.12	15	36	2
20	1	18	.11	.22	.22	.29	.33	.4	.17	15	28	2
3	1⅜	18	.15	.30	.30	.40	.45	.55	.23	15	36	3
21	1⅜	18	.23	.45	.45	.6	.67	.82	.34	15	28	3
4	1¾	18	.30	.60	.60	.80	.90	1.1	.45	15	40	4
10	1¾	18	.39	.78	.78	1.0	1.1	1.4	.58	15	28	4
9	2⅝	18	.58	1.1	1.1	1.5	1.7	2.1	.87	15	28	4
5	2⅝	18	.60	1.2	1.2	1.6	1.8	2.2	.90	15	40	5
11	2⅝	18	.78	1.6	1.6	2.1	2.3	2.8	1.2	15	28	5
12	3⅜	18	.90	1.8	1.8	2.4	2.7	3.3	1.4	15	28	5
13	4⅜	18	1.1	2.2	2.2	2.9	3.3	4.0	1.7	15	28	5
6	3⅜	16	1.2	2.4	2.4	3.2	3.6	4.5	1.8	12	40	6
14	3⅜	16	1.5	3.1	3.1	4.1	4.6	5.8	2.4	12	28	6
15	4⅜	16	1.8	3.5	3.5	4.6	5.2	6.5	2.7	12	28	6
16	4⅜	16	1.9	3.8	3.8	5.0	5.6	7.0	2.9	12	24	6
17	6″ sq.	16	2.7	5.4	5.4	7.2	8.1	10.0	4.1	12	28	6
7	4⅜	14	2.0	4.0	4.0	5.3	6.0	7.5	3.1	12	40	7
18	4⅜	14	2.6	5.2	5.2	6.9	7.8	9.7	4.0	12	28	7
19	6″ sq.	14	3.7	7.4	7.4	9.8	11.1	13.3	5.7	12	28	7
8	8″ sq.	14	5.0	10.0	10.0	13.0	15.0	18.0	7.5	12	28	7

* Note: These ratings do not apply to battery charging or condenser loads.

Table I—Sizes and Current Capacity of Selenium Rectifiers.

be made to maintain a high reverse resistance. A d-c valve which is chiefly used with blocking potential needs no such attention. It should be noted also that the maximum permissible d-c reverse potential is less than the r.m.s. a-c values.

With fan cooling at an air velocity of 55 feet per minute Type 7, for example, gives 150% of the convection cooled current ratings listed in Table I. If the air velocity is increased to 90 feet per minute the ratings are twice the values in the table and at 120 feet per minute, 2½ times the listed values.

In oil at 35° C., the Type 4 Selenium Rectifier gives 167% of the currents indicated in the table.

Regulation

Along with unusual stability of operating characteristics, the exceptionally good voltage regulation of the Selenium Rectifier results from its low forward resistance. Regulation from no load to full load for a single phase bridge rectifier with a resistive load is of the order of 15%. The addition of fins, or wide spacing, for obtaining increased current density may increase this value by about 5%; with highly intermittent use a further increase may occur if too small a rectifier is selected. Fig. 14 shows typical changes in voltage drop across a plate of a single phase bridge type rectifier as its current output is increased. The largest portion of the voltage change occurs from zero output current to some small value of current of the order of 20% of full load. From there on, the voltage change is almost linear and the regulation from, say, half load to full load is only about 6%. The use of a small additional load or bleeder resistance improves the regulation by preventing the output current from decreasing to zero.

Where close regulation is essential, various regulating devices may be employed. Fig. 23 shows a saturable core reactor type of regulating rectifier used for telephone central office power

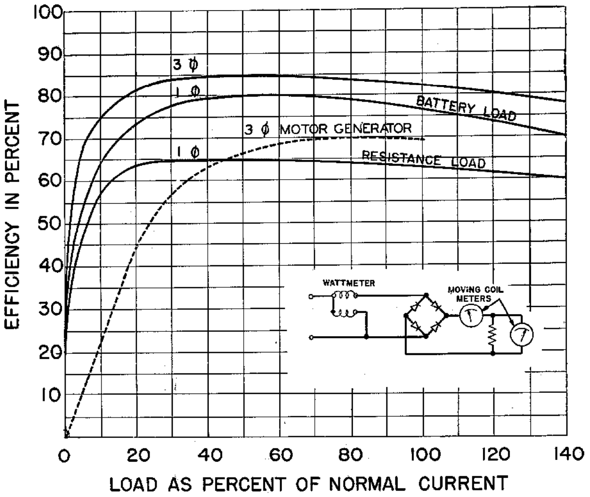


Fig. 24—Efficiency of Selenium Rectifier Operating at Full Load Voltage Compared to Average Typical Efficiency of a Motor Generator Set with Exciter.

supply. One winding of a small reactor is placed in series with the a-c input to the rectifier; the other, is connected in series with the d-c load. If the load current tends to increase, the saturable reactor impedance on the a-c side is decreased and the a-c voltage impressed on the rectifier is immediately increased so as to restore the d-c output voltage. Such rectifiers can be made to almost any small degree of regulation for extremely wide load changes. They serve a wide variety of uses besides simple control of load voltage; an example is the electric milk pasteurizer where the constancy of the pasteurizing temperature is controlled by a saturable core Selenium Rectifier circuit.

When compensation for line voltage fluctuations is desired, taps on the primary of the rectifier transformer may be used or regulation accomplished automatically by the use of one of the standard regulating transformers available. If a rectifier is required for laboratory or test work with variable output voltage, it is convenient to use a continuously variable input transformer to supply the rectifier, making certain that the permissible voltage of the rectifier will not be exceeded.

Efficiency and Economy

In order to take into account the various form factors which differ considerably with various types of load and rectifier arrangements, the efficiency of the Selenium Rectifier is considered to be its volt-ampere efficiency, obtained by a wattmeter measurement of input and a moving-coil voltmeter and ammeter measurement of output. Such measurements show the rectifier efficiency between 65% and 85%, depending on the nature of the circuit and the load. These efficiencies, shown in Fig. 24, apply to convection cooled rectifiers without cooling fins and operation at maximum voltage. The high efficiency is maintained with remarkable uniformity from about 20% to 150% of full load. The Selenium Rectifier differs in this respect from most electrical equipment which normally reaches maximum efficiency only in the neighborhood of full load current. Efficiency of the rectifier, however, is dependent on the operating voltage per plate. The aim of the designer, therefore, should be to provide an adequate but not excessive number of plates for each specific application.

In comparison with tube rectifying equipment, the Selenium Rectifier is usually found to have a higher efficiency for outputs of any current at voltages up to about 80 to 120 volts. Tube equipment ordinarily has a constant internal drop of about 15 volts, regardless of output voltage, whereas the total internal drop of a Selenium Rectifier must rise as its voltage, and hence its number of plates, is increased. Furthermore, tube efficiency is lowered by the filament or heater losses. The efficiency of the Selenium Rectifier therefore is higher in the range within which the loss due to its internal drop is less than the total losses of the tube rectifier.

Rotating machinery, such as the motor generator, compared with the Selenium Rectifier, is about equally efficient at full load, but its efficiency drops off rapidly as the load deviates from full load. With individual machine efficiencies of 80% to 85% or more, the overall efficiency of a motor generator set is about 64% to 72%. Small machines may be less and large machines more efficient.

The use of wider plate spacing or the addition of cooling fins to the Selenium Rectifier, while decreasing its efficiency by some 3% to 5% in most cases, is usually economical where size and first cost are of greater importance than annual charges. This is also true of fan cooled rectifiers, the efficiency of which may drop as much as 10% below the convection cooling values.

Efficiency in Electroplating Applications

Uniformity of the rectifier efficiency with varying output currents suggested applications where the load current is not constant, such as in electroplating. Although electroplating generators possess high efficiency, they must usually be isolated from the plating tanks for protection against corrosion, thus involving long bus bars and considerable power losses due to the heavy currents handled. Since small individual generators are uneconomical, one large constant voltage machine is generally used for serving a considerable number of plating tanks, the voltage at each tank being reduced by a series rheostat with resultant large power losses. Thus the combination of bus and rheostat losses may reduce the overall efficiency of the plating plant to a maximum of some 40% to 45%. A solution of this problem has been effected by the use of compact, forced air cooled or oil immersed Selenium Rectifier units close to the plating tanks to minimize bus bar length. By designing the plating rectifier (Fig. 25) for the required output voltage and using a regulator within the rectifier for close adjustment, tank rheostats can be eliminated. Higher starting costs for rotating machines, the cost of power factor correction and higher standby losses when idling are additional considerations favoring the use of rectifier equipment. Rotating machines, further, are larger in size and heavier than equivalent Selenium Rectifiers and usually require special foundations for supporting and anchoring them. In contrast to these disadvantages, the 1500 ampere Selenium Rectifier illustrated in Fig. 25 has been mounted on small casters so that it may be readily installed and moved at short notice.

Design Requisites

Choice of circuit schemes ordinarily may be left to the rectifier designer. Under certain conditions advantage should be taken of the fact that three phase circuits have a smaller ripple then single phase rectifier circuits and their higher frequency is easier to filter. The ripple in the output of a single phase bridge

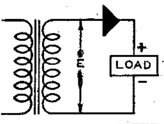
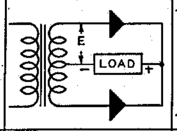
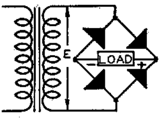
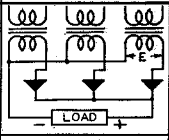
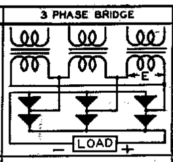
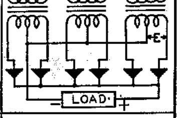
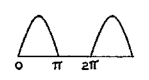
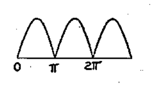
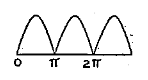
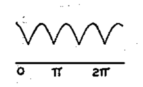
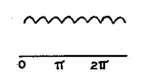
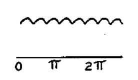
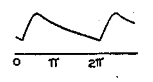
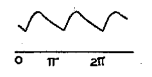
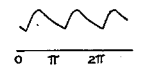
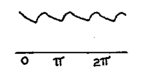
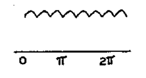
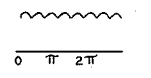
CIRCUIT	SINGLE PHASE HALF WAVE	SINGLE PHASE CENTER TAP	SINGLE PHASE BRIDGE	3 PHASE HALF WAVE	3 PHASE BRIDGE	3 PHASE CENTER TAP
RECTIFIER CONNECTION						
RESISTIVE LOAD APPROXIMATE OUTPUT VOLTAGE WAVE SHAPE						
CAPACITIVE LOAD APPROXIMATE OUTPUT VOLTAGE WAVE SHAPE						
NUMBER OF PLATES IN SERIES E=AC RMS VOLTS V_p=RATED VOLTS PER PLATE	RESISTIVE LOAD $\frac{E}{V_p}$	RESISTIVE LOAD $\frac{2E}{V_p}$	RESISTIVE LOAD $\frac{E}{V_p}$	RESISTIVE LOAD $\frac{\sqrt{3}E}{V_p}$	RESISTIVE LOAD $\frac{E}{V_p}$	RESISTIVE LOAD $\frac{2E}{V_p}$
	CAPACITIVE LOAD $\frac{(1+\sqrt{2})E}{V_p}$	CAPACITIVE LOAD $\frac{2\sqrt{2}E}{V_p}$	CAPACITIVE LOAD $\frac{\sqrt{2}E}{V_p}$	CAPACITIVE LOAD $\frac{(1+\sqrt{2})E}{V_p}$	CAPACITIVE LOAD $\frac{\sqrt{2}E}{V_p}$	CAPACITIVE LOAD $\frac{2\sqrt{2}E}{V_p}$
THEORETICAL RIPPLE	121%	48.3%	48.2%	18.3%	4.2%	4.2%
MAXIMUM THEORETICAL OUTPUT EFFICIENCY $\frac{E_{0DC}\ I_{0DC}}{E_{0AC}\ I_{0AC}}$	40.5%	81.1%	81.1%	96.8%	99.8%	99.8%

Table II—Basic Characteristics of Rectifier Circuits.

rectifier is about 48%. A three phase, half wave circuit produces an 18% ripple; for three phase bridge and center tap circuits, this value is as low as 4%. Inasmuch as the utility factors for three as compared with single phase circuits are more favorable, the resultant three phase rectifiers are smaller and less expensive. Moreover, since operation of the Selenium Rectifier does not depend on the generation of electrons through the agency of heat or the inclusion of contactors, such as commutators, the ripple frequency spectrum, as might be anticipated, is confined to low multiples of the input frequency and does not contain either high frequency noises inherent in thermionic equipment or the transients of commutating machines.

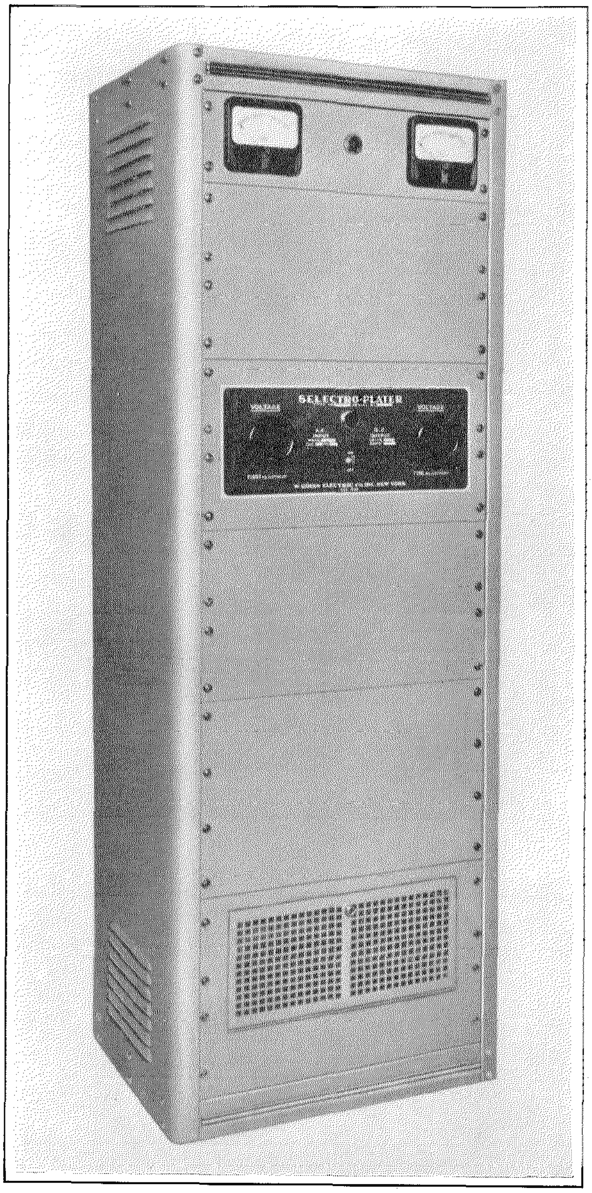


Fig. 25—Electroplating Rectifier, 6 v, 1,500 amp. (Courtesy of W. Green Electric Company.)

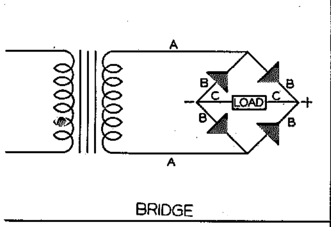
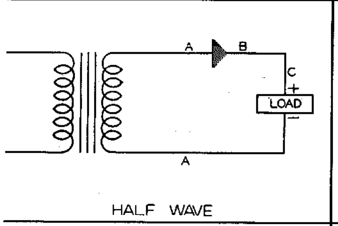
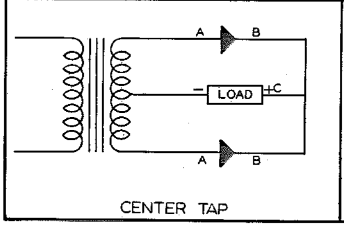
Basic characteristics of the six most common rectifier circuits are listed in Table II.

The single phase half wave circuit is ordinarily not economical except for low voltage and current output since only one-half of the cycle is utilized. As shown in the oscillograms of Table II, the use of a condenser across the load maintains some current flow during the half-cycle which is suppressed by the rectifier. Rectifier reverse current flows through the load.

The single phase full wave bridge arrangement is perhaps most widely used. The ripple voltage has twice the frequency of the a-c supply and the rectifier back current does not flow through the load. If the load is highly inductive, switching on the a-c supply side permits the rectifier to act as an effective means of absorbing the rise in voltage across the load so that when the supply voltage is disconnected, the voltage across the load does not rise appreciably above its normal value. The rectifier may consist of a single stack, two identical stacks each having two bridge arms, four half wave stacks representing each of the four bridge arms, or series-parallel combinations. For a rectifier with a single 18 volt plate per arm, the output voltage is of the order of 12 volts.

The single phase full wave center tap arrangement provides the same performance as the bridge circuit but is only half as large. It is applicable to output voltages of the order of 6 volts or less and requires a center tapped transformer. If the output voltage is higher, the number of plates required will be the same as for the bridge connection and it is then more economical to use the latter circuit since it does not require a center tapped transformer.

The three phase half wave circuit differs from the corresponding single phase arrangement in that current flows through the load throughout the entire cycle due to overlapping of the output from the three phases. It is therefore commercially advantageous because of its higher effi-

SINGLE PHASE	SECTION	RESISTANCE LOAD FACTOR	BATTERY LOAD FACTOR
 BRIDGE	A	1.15	1.7
	B	.80	1.2
	C	1.15	1.6
 HALF WAVE	A	1.80	2.5
	B	1.80	2.5
	C	1.80	2.5
 CENTER TAP	A	.80	1.2
	B	.80	1.2
	C	1.15	1.6

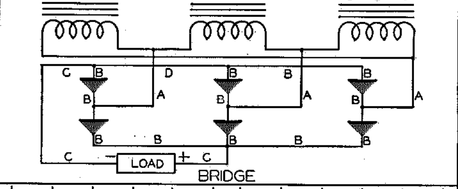
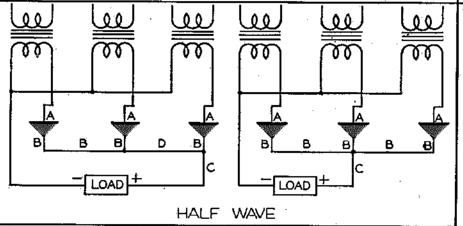
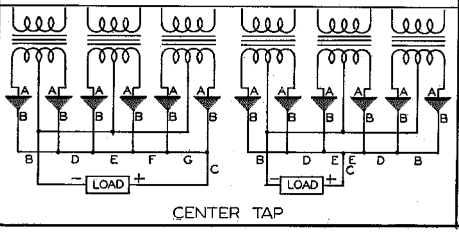
THREE PHASE	SECTION	RESISTANCE LOAD FACTOR	BATTERY LOAD FACTOR
 BRIDGE	A	.85	.86
	B	.60	.61
	C	1.0	1.02
	D	.85	.86
 HALF WAVE	A	.65	.70
	B	.65	.70
	C	1.06	1.08
	D	.86	.90
 CENTER TAP	A	.46	.48
	B	.46	.48
	C	1.00	1.02
	D	.62	.64
	E	.75	.77
	F	.85	.87
	G	.95	.97

Table III—Approximate Current Factors in Rectifier Circuits.

ciency and low ripple component. The ripple frequency is three times that of the supply line.

The three phase bridge circuit is one of the most useful for large power outputs; it has the highest efficiency and the lowest ripple voltage. The ripple frequency, six times that of the power supply, may easily be filtered out.

The three phase center tap circuit is similar in connection to the single phase equivalent. It offers the same performance as the three phase bridge connection but has a lower voltage output per plate. The number of arms in the rectifier is the same as for the three phase bridge circuit, yet the permissible forward current per plate is higher than that for the three phase bridge connection since the current of one phase returns directly to that phase from the load and does not divide between the other phases as in the three phase bridge rectifier.

Approximate current factors in these rectifier circuits, especially useful in the determination of wire and bus bar sizes, are given in Table III. With a known output current, the effective current in each section of the various circuits can be determined by multiplying the mean or average value of the output current by the appropriate factor.

Essential Design Data

In order to design a rectifier for a specific application, an outline of the limiting conditions is required. A circuit schematic including constituent electrical constants conveys the clearest definition of the operating requirements and frequently enables the designer to suggest alternate arrangements warranting consideration. Actual performance requirements and details of service conditions are preferable to the inclusion of arbitrary safety factors. While Selenium Rectifier ratings embody ample safety factors, careful design is essential in order that all limiting conditions may be met without sacrificing desirable margins or unduly increasing others.

Obvious requirements include d-c output voltage and current. Stated tolerances for each aid the designer, whose choice is limited to fixed current and voltage steps. First cost usually is a function of rectifier output and varies with the number of plates required, making it desirable to hold size to a minimum. The number of phases of the power supply is important but the frequency is relatively unimportant except for capacitive loads or smoothing filter circuits inasmuch as the rectifier ratings hold for frequencies up to 1000 cycles per second. Voltage variation of the a-c supply line should be stated.

Upper and lower ambient temperature limits must be known as well as the duty cycle, i.e., whether continuous or intermittent. If the latter, details of current changes are required together with the length of time each value is to be maintained, as well as the length of each "off" period. Necessary also are voltage regulation limits between stated loads and details of switching, i.e., whether on the line or load side of the rectifier.

The nature of the load is an important design factor. Inductive and resistive loads are usually treated similarly, but capacitive loads and battery charging service require different designs. For capacitive loads, the value of the capacity and the supply line frequency must be known in order to determine the a-c input to the rectifier. If a filter is used, it is considered as an inductive or capacitive load according to whether its input section comprises a choke coil or a condenser. Battery charging should be defined as either taper or trickle charging. If the former, the maximum starting rate and the final cell voltage must be known. For trickle charging, similarly, the charging rate and cell voltage must be defined together with data on maximum cell voltage required if the battery is to be given an occasional "freshening" charge.

Atmospheric conditions require attention in order to determine whether or not a protective coating should be applied to the rectifier. Such a coating does not alter the rectifier rating.

The a-c voltage required for a given d-c output voltage depends on the circuit and load conditions. For a resistive or inductive load, the r.m.s. input voltage of a single phase bridge rectifier is of the order of 30% above the mean output voltage; for a three phase bridge rectifier, the input voltage is about 12% below the mean output voltage. Similarly, for a single phase, half wave rectifier the input voltage is about 180% above the output; and, for a three phase half wave rectifier, it is about 8% above the output. In a single phase bridge rectifier operating into a capacitive or trickle charging load, the input and output voltages are about equal numerically. While this may reduce the number of rectifier plates in series, the current capacity of the rectifier must be increased by about 12% as compared with a resistive or inductive load.

The rectifier designer, in addition to stated line voltage, ambient temperature and other known variables, must consider full compensation for aging as well as allowances for variation in ventilating conditions. The usual practice is to mount rectifier stacks at or near the bottom of the equipment housing so that they will receive an unrestricted supply of air at about the prevailing temperature. If two or more stacks are required in the rectifier unit, it is generally preferable to mount them side by side rather than one above the other.

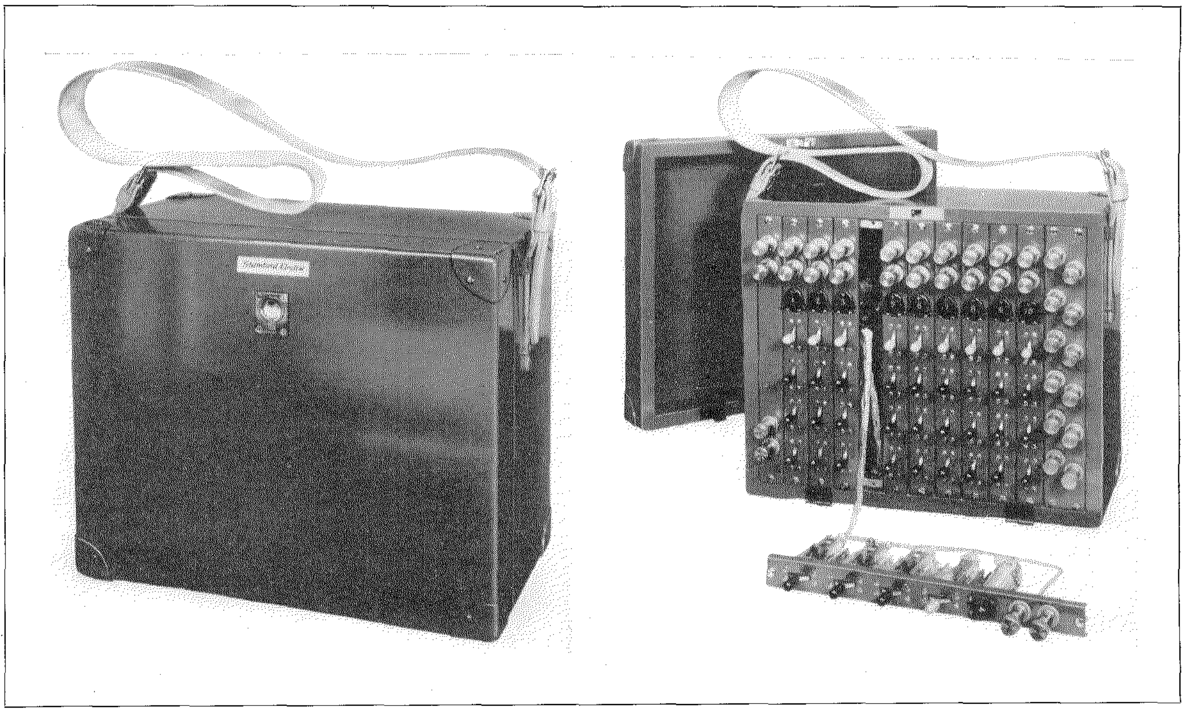
The housing for the complete equipment should preferably be small in horizontal cross sectional area and as high as practicable in order to enhance "chimney" action for convection cooling.

Recent Telecommunications Developments

Portable Switchboard.—Standard Electric NMS-10 local battery portable switchboard, providing facilities for ten lines and six connecting circuits, is specially designed to withstand rough usage in the field. Connections are effected by means of rugged switching keys, no cords being utilized. The apparatus required for each line circuit, i.e., binding posts, drop and switching keys, is mounted on an individual panel, arranged for convenient disconnection without disturbing other circuits and thus facilitating field maintenance.

The quartered oak protecting cabinet, finished in olive drab, is 15$\frac{5}{16}$ inches wide, 13$\frac{1}{4}$ inches high and 8 inches deep; its weight is 35 lbs.

Two switchboards can readily be interconnected and operated by one person when facilities exceeding ten lines are required.



"Normas sobre Receptores de Radio," a translation from English into Castilian of I.R.E. "Standards on Radio Receivers 1938" has been issued by the Sección Buenos Aires of the Institute of Radio Engineers, Inc. The following is quoted (in translation) from the foreword incorporated in the Castilian edition:

"On May 2, 1939, the members of the Institute of Radio Engineers residing in the Argentine, numbering 25, decided to form a local association for greater technical efficiency and collaboration.

"The association, which took the name, Centro Argentino de Socios del Institute of Radio Engineers, requested the central headquarters in New York to recognize it as an Official Section. This was accorded by the Board of Directors of the Institute at its meeting on October 4th of the same year.

"Recognized as an Official Section, the association as of that date chose the name 'Sección Buenos Aires' of the Institute of Radio Engineers.

"This Section is the only one existing outside the North American continent and is the first Spanish-speaking one. The Sección Buenos Aires, consequently, has felt itself called upon to translate into Castilian the standards prepared by the

Institute, desiring thus to fulfill its fundamental purpose, which is to contribute to the dissemination of radioelectric knowledge.

"The present Managing Committee of the Sección Buenos Aires comprises:

A. T. COSENTINO	*Chairman*
A. M. STEVENS	*Ex-Chairman*
P. J. NOIZEUX	*Vice-Chairman*
G. J. ANDREWS	*Secretary-Treasurer*
E. E. KAPUS J. P. ARNAUD A. NADOSY	*Members*

"Translation of the standards was prepared by an Argentine committee, under the supervision of J. P. Arnaud and M. J. Kobilsky."

Copies of "Normas sobre Receptores de Radio" may be obtained from Revista Telegrafica, Peru 165, Buenos Aires, at a price of one Argentine peso.

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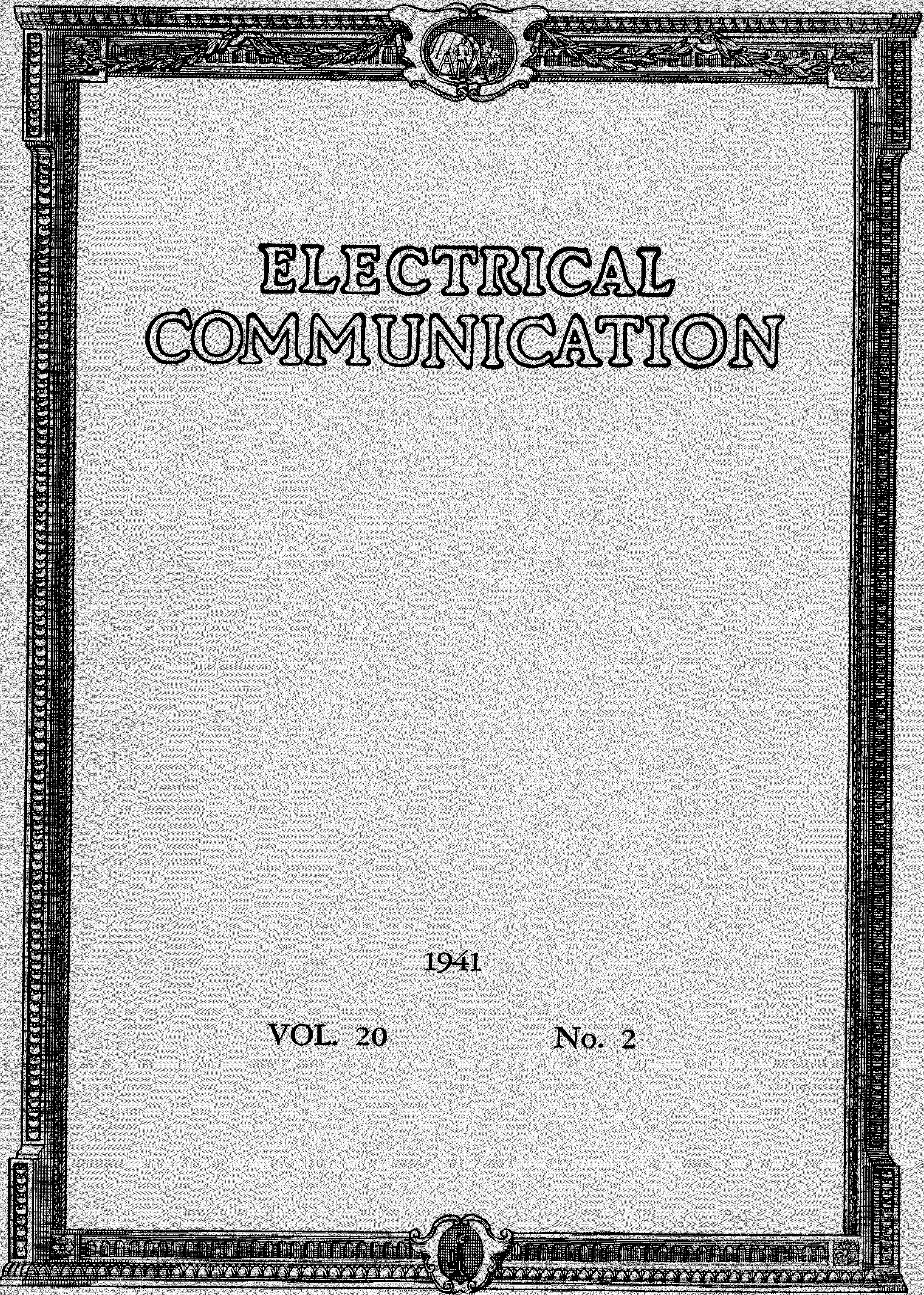
Printed in U.S.
4108

Mr H. J. D. Shrimpton. N.W.



ELECTRICAL COMMUNICATION

1941

VOL. 20 No. 2

ELECTRICAL COMMUNICATION

A Journal of Progress in the Telephone, Telegraph and Radio Art

H. T. KOHLHAAS, Editor

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Published Quarterly by the
International Standard Electric Corporation
67 BROAD STREET, NEW YORK, N.Y., U.S.A.

H. M. Pease, President S. G. Ordway, Secretary and Treasurer

Subscription, $3.00 per year; single copies, 75 cents

Volume XX 1941 Number 2

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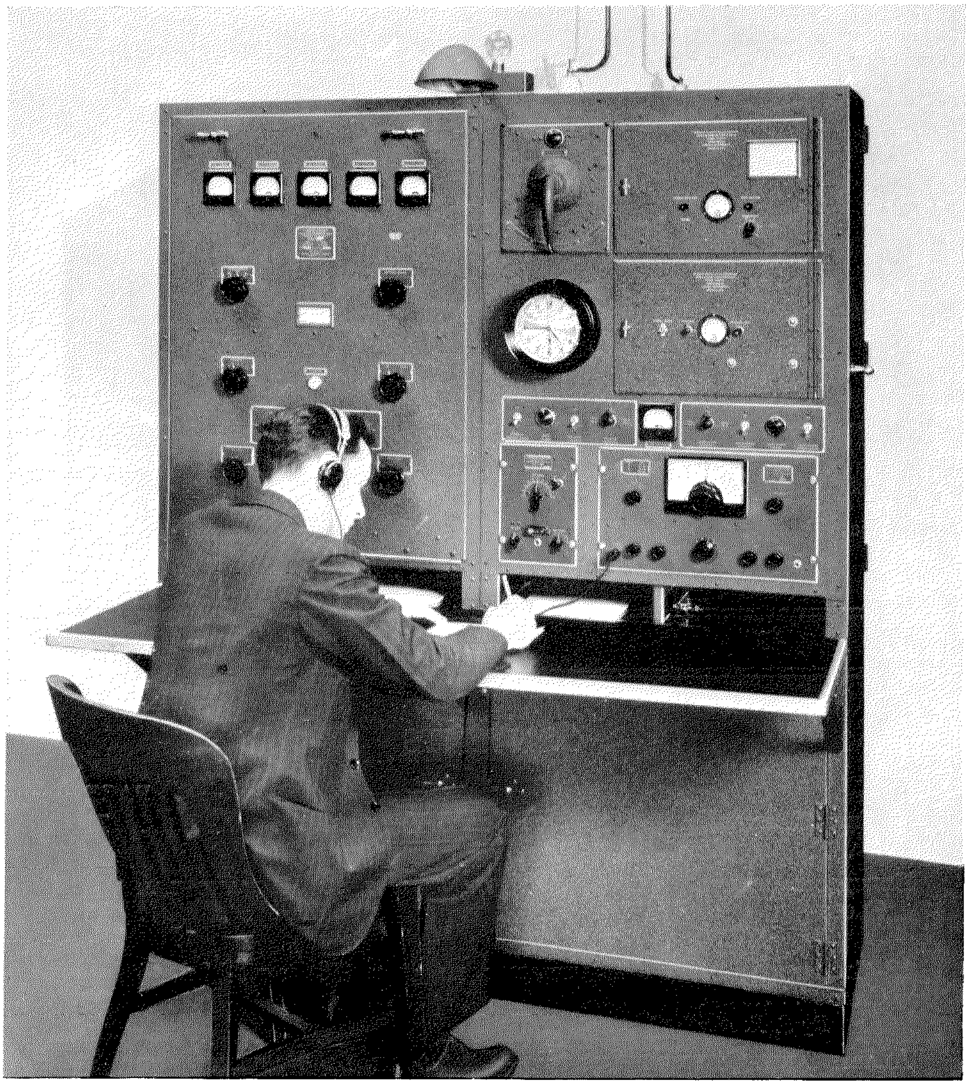

A New Marine Radio Unit for Cargo Vessels.

THIS NEW DEVELOPMENT PROVIDES ALL NECESSARY FACILITIES FOR SAFETY AND COMMUNICATION PURPOSES AND COMBINES, IN A SINGLE COMPACT CABINET, EQUIPMENT WHICH ORDINARILY COMPRISES AS MANY AS TWELVE SEPARATE UNITS. INSTALLATION IS GREATLY SIMPLIFIED INASMUCH AS THE UNIT IS PRACTICALLY READY TO "PLUG IN" FOR POWER SUPPLY AND ANTENNA CONNECTION.

THE SET WAS DESIGNED AND IS BEING MANUFACTURED BY THE FEDERAL TELEGRAPH UNIT OF THE INTERNATIONAL TELEPHONE AND RADIO MANUFACTURING CORPORATION.

A New Marine Radio Unit for Cargo Vessels

By E. J. GIRARD

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Historical

THE need for ship-to-ship and ship-to-shore communications, primarily involving safety considerations, provided the incentive which led to the early development of radio. Despite the fact that spectacular developments in radio during the past forty odd years have tended to obscure the importance of ship radio facilities in the public eye, marine radio nevertheless remains one of radio's most essential applications.

From 1914 on the Federal Telegraph Company has supplied marine radio equipment on a large scale, emphasizing efficiency, reliability and safety. It pioneered in the development of CW equipment of the arc transmitter type, and, in more recent years, in collaboration with the Mackay Radio & Telegraph Company, it offered to U. S. A. shipowners the first combined intermediate and high frequency transmitter, as well as the first transmitter contained in one panel capable of operating both from the ship's power supply and from a low voltage, high capacity emergency storage battery.

During the years 1920–37 the demand for ship radio facilities was mainly for additions or replacements to existing equipment rather than for complete new installations. For example, during this interval many 50 watt emergency transmitters were added to existing installations. The outlawing in 1930 of new spark transmitter installations, as well as obsolescence of such transmitters in service, created a substantial demand for intermediate wave tube type transmitters. The development of high frequency marine equipment led to the installation of high frequency transmitters and receivers on shipboard. Following the establishment of United States Government requirements in 1937, U. S. A. cargo vessels, with certain exceptions, have been equipped with auto alarm apparatus for the reception of the International Auto Alarm Signal.

Furthermore, during this period (1920–37), comparatively few new merchant vessels were constructed in the U. S. A. Ships actually built were of various designs and sizes and large scale standardization was not attempted.

Conditions prevailing during the past twenty years thus hardly encouraged departure from the established practice of "packaging" individual units in the form of transmitters, receivers, etc. Accordingly, on the majority of older vessels, installations, like Topsy, "just grew." On newer vessels, similarly, radio installations comprised various individual units more or less conveniently supported on tables or bulkheads. Interconnections were made at the time of installation, involving a lengthy and expensive procedure.

In 1936, the U. S. Maritime Commission succeeded the U. S. Shipping Board as the Government's shipping and shipbuilding organization and immediately initiated an ambitious construction program calling for the building of 500 ships over a ten year period. The resulting increased demand for radio facilities, however, was generally met by types of equipment already in existence.

An opportunity for the development of a complete unit, combining in a single cabinet all the ship radio facilities required, was presented by the inauguration of the emergency cargo vessel building program formulated by the Maritime Commission as part of the National Defense Program. The Federal Telegraph Company took advantage of this opportunity and has successfully concluded the development of a complete shipboard radio unit described hereinafter.

New Marine Radio Unit

A view of the new marine radio unit is shown in the Frontispiece. The equipment at the left is the main and emergency transmitter. When used as the main transmitter, the output on CW and MCW is in excess of 200 watts and 300 watts, respectively. When functioning as the emergency transmitter, the output is in excess of 50 watts. Hinging of the transmitter panel at the bottom enables it to be swung downward and provides ready accessibility for servicing, etc. Quick changeover can be effected on five predetermined frequencies in the operating range of 350 to 500 kc.

The antenna switch (see Frontispiece) is located in the right hand section of the unit; it provides for auto alarm operation, direction finding position, main antenna and ground. The auto alarm panels comprise a receiver and a selector; they are shown to the right of the antenna switch and clock, respectively. Both can be swung forward providing complete accessibility from the front. The auto alarm unit operates continuously while the operator is off watch and is responsive to the International Auto Alarm Signal on the distress frequency of 500 kc.

Below the auto alarm are the controls for the battery charging and power facilities. The charging units are located towards the rear of the cabinet. A blower at the back of the cabinet circulates air corresponding to the number of chargers in use at a given time. Adequate ventilation and cooling are thus assured.

Two receivers are shown in the right hand section immediately above the operating shelf. The main receiver covers an operating range of 15 to 650 kc. It utilizes a tuned radio frequency circuit and is especially constructed for marine use. Suitable filtering and shielding insure freedom from electrical interference due to nearby equipment. The second receiver, situated at the left of the main receiver, is of the crystal detector type required by law. It serves as a standby in case the main receiver becomes inoperative. Both receivers can be pulled out from the front so that they are completely accessible.

The operating shelf is 18 inches deep and replaces the conventional radio room table.

Below the operating shelf, sections accessible through hinged doors house two motor generators. One machine energizes the transmitter at full power from the ship's mains; the other operates the main transmitter from a 24 volt storage battery.

Installation

Installation of the combination unit equipment on shipboard consists chiefly in securing the unit in place in the radio room and connecting the antenna and power leads. Estimates indicate that these operations can be completed in not more than one-fifth of the time necessary to install an equivalent installation of the ordinary type comprising separately placed transmitters, receivers, motor-generator sets, etc. The wiring problem, obviously, is greatly simplified. The importance of this saving in time and expense is apparent when it is considered that the installation of radio equipment on new vessels usually requires from six weeks to two months. Moreover, such installations tend to interfere with concurrent construction work on the ship itself. With the new Marine Radio Unit, on the other hand, practically all work on the ship can be completed prior to the time the radio room unit is placed in the position designated.

Important to naval architects and to others is the fact that radio room space requirements can be readily and accurately pre-determined.

When convenient for shipment or necessary for passage through doors or corridors on shipboard, the unit can be separated into two equal sections, each measuring 69½×29×19 inches. The operating shelf is, of course, demountable.

Standardization

The new combined unit standardizes the position of operating controls and thereby expedites and simplifies the training of radio operators. Regardless of the ship on which the equipment is to be installed, all controls are at the operator's finger tips in exactly the same relationship on each ship. Hence, servicing and operating instructions can be simplified and made more specific, and operators should find it easier to become familiar with the equipment.

As mentioned above, the new Marine Radio Unit resulted from the program of mass production of merchant vessels in the U. S. A. It is, however, suitable for any type or size of ship, and indications are that it will meet with a wide demand from ship owners and ship builders.

Electromagnetic Waves in Metal Tubes of Rectangular Cross-section*

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The attenuation of electromagnetic waves propagated through the interior of metal tubes of rectangular cross-section is calculated by the familiar telephone transmission formulae, the top and bottom of the tube being regarded as zigzag flat-strip transmission lines while the side walls are regarded, when suitably disposed, as transmission lines of another type. From the losses occurring in these lines, the attenuation offered by the tube is obtained in a simple manner. The results are found to be in agreement with those established by more elaborate means by other investigators. The characteristic advantage of the method here described is its simplicity and the directness with which the final results emerge. The method also provides a link between electrical communication through the interior of hollow metal tubes and the transmission of waves along telegraph and telephone lines of conventional type.

(1) *Introduction*

WITHIN the last few years a number of contributions have been made to the subject of electromagnetic waves in hollow metal tubes. Although the existence of such waves has been known for a long time and although their theory was clearly stated in 1897 by Lord Rayleigh,[1] it is only recently that consideration has been given to them from the point of view of long-distance communication[2, 3, 4, 5, 6, 7, 8, 12] and that their attenuation has been calculated. The general formula for the attenuation of all types of waves in metal tubes of all cross-sections has been established by Schelkunoff.[6] Chu and Barrow[7] have also derived attenuation formulae for all types of waves supported by tubes of rectangular cross-section. The method followed thus far has involved the computation of the energy flow in the direction of the tube and the power losses in the walls by means of the Poynting flux theorem. It is proposed here to show that the same expressions for the attenuation can be derived from the ordinary telephone transmission formulae. Although this simple treatment of the problem can be applied only to one class of waves, it furnishes a link between the transmission of waves through hollow metal tubes and the transmission over telephone and telegraph lines of familiar type.

Electromagnetic waves in metal tubes are characterized by two essential features. There is a minimum frequency below which no waves are supported by the tube. This minimum or cut-off frequency is determined by the shape and the size of the tube. As the wavelength of the cut-off frequency is of the order of the cross-sectional dimension of the tube, the frequencies of the possible waves—for air-filled tubes having dimensions in the centimetre range—are of the order 10^9 cycles per second and above. The second feature is that there is either an electric or a magnetic intensity in the direction of propagation of the waves, i.e., along the tube. For electromagnetic waves in free space the electric and the magnetic intensities are in planes at right angles to the direction of propagation. When, however, waves are restricted to the inside of metal tubes there is, in addition to the electric and magnetic intensities of the free-space waves, either an electric or a magnetic intensity in the direction of propagation. It is customary to use this additional property of these waves for their classification. When there is an electric intensity in the direction of propagation, the wave is designated an E-wave. When there is a magnetic intensity in the direction of propagation, the wave is designated an H-wave. Subscripts are used for further classification; thus the subscripts "n, m" designate a wave of order n and of mode m. The order and the mode of a wave are determined by the number of half or full sinusoidal variations of the electromagnetic field along certain specified directions of the cross-section. For a rectangular tube only half-sinusoidal variations are taken into account, so

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* Wireless Section I. E. E. paper. Reprinted from Part III, *Journal I. E. E.*, Sept., 1941.

that n designates the number of half-sinusoidal variations between the top and bottom walls of the tube, and m the number of half-sinusoidal variations between the two side walls of the tube. If the field does not vary between the top and bottom, n is zero and the wave is designated a zero-order wave.

The waves for which the attenuation will be considered here are H-waves of zero order, i.e., $H_{o,m}$ waves, and the cross-section of the tube is assumed to be a rectangle of height a cm. and width b cm. The principal wave of this class, i.e., the $H_{o,1}$ wave, has been the subject of detailed study by Chu and Barrow.[7] As the cut-off frequency and the attenuation of this wave are lower than those of any other wave in a rectangular tube, it offers the best prospect for practical application.

Being of zero order, all waves of the $H_{o,m}$ class are characterized by the fact that their electric intensity is parallel to the side walls. Across the width of the tube the variations of the electric intensities follow sine curves as in Fig. 1. The wave of lowest mode, i.e., the $H_{o,1}$ wave, possesses one half-sinusoidal variation, the wave of next higher mode, i.e., the $H_{o,2}$ wave, possesses two half-sinusoidal variations, and so on. In addition there is, of course, a space variation along the tube, i.e., in the direction of propagation, and the usual time variation.

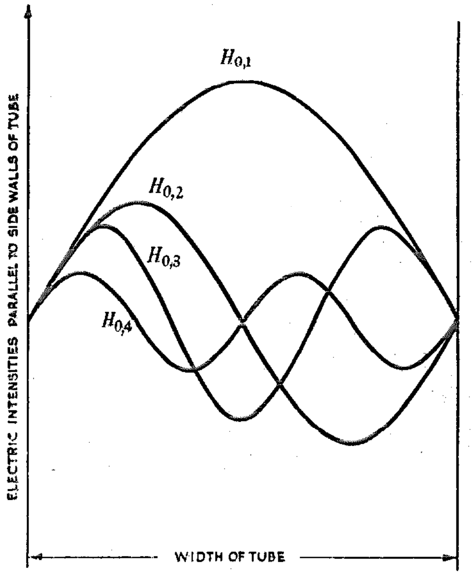

Fig. 1—Distribution of Electric Intensities of Some Waves of the $H_{o,m}$ Class.

The cut-off frequencies of the waves of the $H_{o,m}$ class are determined by the expression $mv_1/(2b)$, where v_1 is the velocity of propagation of an electromagnetic disturbance in free space. When the dielectric within the tube is air, v_1 is $3 \cdot 10^{10}$ cm. per sec. These waves have, for the purpose of calculations, been resolved[7] into a pair of plane waves travelling across the tube with a velocity corresponding to that of plane waves in an unrestricted medium and reflected at the walls of the tube, thus constituting a number of zigzag paths. The angle between the direction of propagation of a component wave and the tube itself is then related to the frequency f and the cut-off frequency $f_{o,m}$ by the equation $\sin\theta = f_{o,m}/f$. This mode of regarding the propagation of a wave in a tube as the result of repeated reflections was first suggested by Brillouin[5] and was also described by Page and Adams.[10] It is a convenient concept for the purpose of explaining some of the properties of these waves and will be used here for calculating the attenuation. Calculations relating to cross-sections other than rectangular are, for the present, in abeyance.

(2) *Outline of Method*

It will be assumed that a tube of rectangular cross-section is filled with homogeneous dielectric and that its walls are of highly conducting material. Let it for the moment be imagined that the side walls are removed and that the top and bottom walls of the tube are cut up—not physically but in imagination—into a number of strips of equal width as in Fig. 2, making

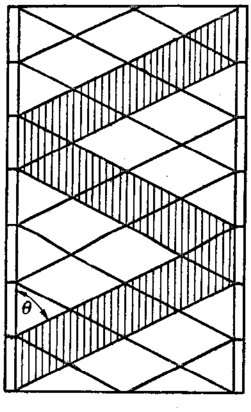

Fig. 2—Plan of Rectangular Metal Tube, Illustrating Mode in Which the Top and Bottom Walls are Imagined to be Cut into Zigzag Paths (One Path Shown Shaded).

an angle θ with the left-hand edge. A similar set of strips starts from the right-hand edge, disposed as in the figure, so that the two sets of strips form zigzag paths. One of these zigzag paths is shown shaded. With each zigzag path of the top wall there is associated a corresponding zigzag path of the bottom wall. Each pair may be regarded as a uniform flat-strip transmission line along which a plane wave may be propagated, the tubes of electric force stretching from top to bottom and sweeping along the zigzag strips, while the adjacent strips serve as electric potential guard-planes to maintain the uniformity of the field. This flat-strip transmission line will be referred to as the "zigzag" line.

Next, the conducting side-walls are to be imagined as being cut into "slabs" as in Fig. 3, their number corresponding to the number of vertices of the zigzag lines. Each "slab" is to be conceived as a semi-infinite flat-strip transmission line in the direction of its thickness and having the wall material as its "dielectric." They will be referred to as "slab" lines. This idea of regarding a slab of metal as a telephone transmission line was suggested and applied in 1915 by Howe[13] to skin-effect problems. Owing to the large difference between the characteristic impedance of a slab line and that of a zigzag line, a slab line, if connected with a zigzag line, will reflect most of the energy arriving at the junction. A small portion, however, will enter the slab line and it is this part that will be calculated from the impedance ratio of the two lines, employing the usual formula. The effect of the presence of the slabs upon the characteristics of the zigzag line will not be considered here except so far as the attenuation is concerned, for which an additional term will emerge from the losses in the "slabs."

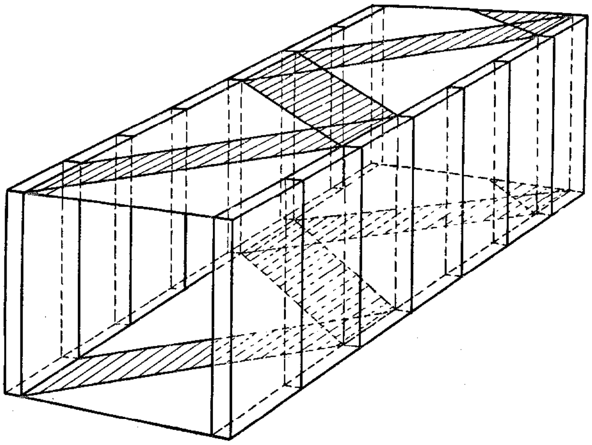

Fig. 3—Hollow Rectangular Metal Tube. Top and Bottom Walls (for Clearness Shown as Having No Thickness) Imagined to be Cut into Zigzag Transmission Lines (One Line Shown Shaded). The Side Walls of the Tube Imagined as "Slabs" Forming Semi-infinite Transmission Lines in the Direction of their Thickness.

(3) *Attenuation for Principal Wave*

For simplicity, attention is first directed to the principal wave, i.e., the $H_{o,1}$ wave of Fig. 1. Results are later extended to waves of higher mode. Following other writers on this subject a practical system of units is here adopted.* Unless stated otherwise, the subscript 1 refers to the zigzag line and subscript 2 to the slab line. The following notations are used:—

L_1, L_2 = inductance, in henrys per cm.
C_1, C_2 = capacitance, in farads per cm.
R_1, R_2 = resistance, in ohms per cm. loop.
G_1, G_2 = leakance, in mhos per cm.
a = distance between the two flat strips, in cm.
w_1, w_2 = width of the strips, in cm.
κ_1, κ_2 = permittivity, in farads per cm. cube $\left(\text{for air } \kappa=\frac{10^{-11}}{36\pi}\right)$
μ_1, μ_2 = permeability, in henrys per cm. cube, of the dielectric in the tube, and of the wall material (for air $\mu=4\pi\times10^{-9}$).
σ_1, σ_2 = conductivity, in mhos per cm. cube, of the dielectric in the tube, and of the wall material (for copper $\sigma_2=5\cdot8\times10^5$).
Z_1, Z_2 = characteristic impedance, in ohms.
γ_1, γ_2 = propagation constant per cm. of line.
α_1, α_2 = attenuation constant per cm. of line.
β_1, β_2 = phase constant per cm. of line.
v_1, v_2 = velocity of propagation in cm. per sec.
θ = angle between zigzag line and edges of tube.
b = width of tube, in cm.
f = frequency, in cycles per sec.
$f_{o,1}$ = cut-off frequency of the principal wave, i.e., the $H_{o,1}$ wave.
$\omega=2\pi f$.
$\nu_{o,1}=\frac{f_{o,1}}{f}=\sin\theta$
δ = loss angle of dielectric $\left(\tan\delta=\frac{\sigma_1}{\omega\kappa_1}\right)$
$K=\sqrt{\left(\frac{2\pi\mu_2}{v_1\sigma_2\mu_1^2}\right)}$.

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* Vide first footnote of Schelkunoff's article, reference (9).

The parameters of a uniform flat-strip transmission line provided with guard planes may be obtained from those of a co-axial cable* if its radius is allowed to increase indefinitely, thus·

$$\left.\begin{aligned} L_1&=\frac{a}{w_1}\mu_1\\ C_1&=\frac{w_1}{a}\kappa_1\\ R_1&=\frac{1}{w_1}\sqrt{\left(\frac{4\pi f\mu_2}{\sigma_2}\right)}\\ G_1&=\frac{w_1}{a}\sigma_1 \end{aligned}\right\}\qquad(1)$$

It will first be assumed that there are no losses in the dielectric. This is the case when the dielectric is air. An adjustment for dielectric losses will be made subsequently. Expressions for the characteristic impedance and for the propagation constant are obtained by substituting the above values (1) in the usual formulae for a uniform transmission line:

$$\left.\begin{aligned} Z&=\sqrt{\left(\frac{R+j\omega L}{G+j\omega C}\right)},\\ \gamma&=\sqrt{[(R+j\omega L)(G+j\omega C)]}. \end{aligned}\right\}\qquad(2)$$

For the attenuation constant of the zigzag line the following convenient formula also is valid in the frequency range concerned:—

$$\alpha=\frac{R}{2}\sqrt{\frac{C}{L}}+\frac{G}{2}\sqrt{\frac{L}{C}}.\qquad(3)$$

In using these formulae certain terms are negligibly small compared with others for frequencies of the order 10^9 appertaining to such waves, and for conductivities of the wall material of the order 10^5. With these adjustments, and using the relation $f_{o,1}=v_1/(2b)$, the formulae reduce to:—

$$Z_1\simeq\sqrt{\left(\frac{j\omega L_1}{j\omega C_1}\right)}=\frac{a}{w_1}\sqrt{\frac{\mu_1}{\kappa_1}}\qquad(4)$$

$$\gamma_1\simeq j\omega\sqrt{(L_1C_1)}=j\omega\sqrt{(\mu_1\kappa_1)}=j\frac{\omega}{v_1}=j\beta_1\qquad(5)$$

$$\alpha_1=\frac{1}{a}\sqrt{\left(\frac{\pi f\mu_2\kappa_1}{\sigma_2\mu_1}\right)}=K\frac{b^{-\frac{1}{2}}}{2a}\nu_{o,1}^{-\frac{1}{2}}\qquad(6)$$

where $K=\sqrt{[2\pi\mu_2/(v_1\sigma_2\mu_1^2)]}$ is a constant depending only on the materials composing the tube.

For the slab line the primary constants are

$$\left.\begin{aligned} L_2&=\frac{a}{w_2}\mu_2,\\ C_2&=\frac{w_2}{a}\kappa_2,\\ R_2&=\frac{1}{w_2}\sqrt{\left(\frac{4\pi f\mu_2}{\sigma_2}\right)},\\ G_2&=\frac{w_2}{a}\sigma_2. \end{aligned}\right\}\qquad(7)$$

Again omitting all negligible terms in calculating the characteristic impedance and the propagation constant, the formulae become

$$Z_2\simeq\sqrt{\left(\frac{j\omega L_2}{G_2}\right)}=\frac{a}{w_2}\sqrt{\left(\frac{j\omega\mu_2}{\sigma_2}\right)},\qquad(8)$$

$$\begin{aligned}\gamma_2\simeq\sqrt{(j\omega L_2G_2)}&=\sqrt{(j\omega\mu_2\sigma_2)}\\ &=(1+j)\sqrt{(\pi f\mu_2\sigma_2)}.\end{aligned}\qquad(9)$$

Thus

$$\alpha_2=\beta_2=\sqrt{(\pi f\mu_2\sigma_2)}.\qquad(10)$$

Since the orders of magnitude of f, μ_2 and σ_2 are respectively 10^9, 10^{-8} and 10^5, it follows that the attenuation constant of the slab line is of the order 10^3 per cm. Hence for all practicable wall thicknesses the line may be regarded as semi-infinite.

The appropriate widths of the two lines are determined by their common boundary at a vertex of the zigzag, which for convenience may be assumed to be 1 cm. Fig. 4 shows this junction in detail. It follows that the width of the zigzag lines must be taken as sin θ, which is equal to $f_{o,1}/f$ or $\nu_{o,1}$. For the slab lines it has been

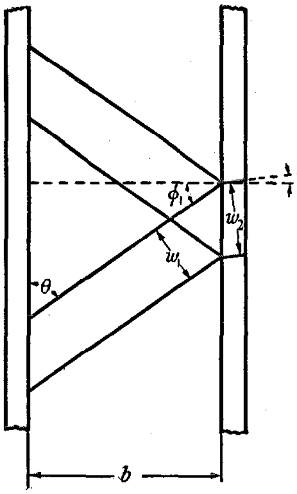

Fig. 4—Junction of "Zigzag" Line and "Slab" Line.

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* Vide A. Russell: "Alternating Currents," Vol. 1, Chap. VII.

assumed, so far, that the cuts are made at right angles to the edges of the tube, the width of the "slabs" thus being 1 cm. Within the range of frequencies and conductivities under consideration this mode of cutting the walls is the appropriate one; for, if the cuts were made at an angle other than 90° as in Fig. 4, the width would be $\cos\phi_2$. Then, since by (5) and (9)

$$\frac{\sin\phi_1}{\sin\phi_2}=\frac{\gamma_2}{\gamma_1}=\sqrt{\left(\frac{-ju_2\sigma_2}{\omega\kappa_1\mu_1}\right)},$$

$$w_2=\sqrt{\left(1+\frac{\omega\kappa_1\mu_1}{j\mu_2\sigma_2}\sin^2\phi_1\right)}\backsimeq 1,$$

the order of the second term under the radical being 10^{-4} or less. Hence ϕ_2 may be regarded as zero. Substituting the values found for the widths of the strips into (4) and (8), the impedances become

$$Z_1=\frac{a}{\nu_{o,1}}\sqrt{\frac{\mu_1}{\kappa_1}}, \tag{11}$$

$$Z_2=a\sqrt{\left(\frac{j\omega\mu_2}{\sigma_2}\right)}. \tag{12}$$

When the dielectric is air and the wall material copper, Z_1 always exceeds $377a$ ohms irrespective of the frequency, while $|Z_2|$ is smaller than a, even for frequencies of the order 10^{12} cycles per sec.

Attention is next directed to the losses occurring at the junction of the lines. If the impedance ratio at the junction is denoted by $u=Z_1/Z_2$, the ratio of the energy entering the slab line and the energy arriving at the junction is given by the formula $4u/(1+u)^2$. The loss expressed as an attenuation is therefore $2u/(1+u)^2$ of which only the real part is to be taken.

Since

$$u=\frac{1}{\nu_{o,1}}\sqrt{\left(\frac{\sigma_2u_1}{j\omega\mu_2\kappa_1}\right)}=(1-j)\nu_{o,1}^{-1}\sqrt{\left(\frac{\sigma_2\mu_1}{2\omega\mu_2\kappa_1}\right)}$$

the loss is

$$\frac{2u}{(1+u)^2}\backsimeq\frac{2}{u}=(1+j)\nu_{o,1}\sqrt{\left(\frac{2\omega\mu_2\kappa_1}{\sigma_2\mu_1}\right)}$$

and the real part of this is

$$Kb^{-\frac{1}{2}}\nu_{o,1}^{\frac{1}{2}}, \tag{13}$$

where again use has been made of the relation $f_{o,1}=v_1/(2b)$.*

Now the length of the zigzag line from one side of the tube to the other is seen from Fig. 4 to be $b/\sin\theta$ or $b/\nu_{o,1}$. Hence if the loss occurring at the junction is distributed over this length and added to the attenuation constant (6) obtained above, the following approximation for the total attenuation constant of the zigzag line with "slabs" is obtained:—

$$\alpha_{\text{total}}=K\left(\frac{b^{-\frac{1}{2}}}{2a}\nu_{o,1}^{-\frac{1}{2}}+b^{-\frac{3}{2}}\nu_{o,1}^{\frac{3}{2}}\right). \tag{14}$$

This is the attenuation constant per centimetre of line. To obtain the attenuation constant per centimetre length of the tube, (14) has to be divided by $\cos\theta$ or $(1-\nu_{o,1}^2)^{\frac{1}{2}}$, the final result for the attenuation constant for the $H_{o,1}$ wave thus being:

$$\alpha_{H_{o,1}}=Kb^{-\frac{3}{2}}\left(\frac{b}{2a}\nu_{o,1}^{-\frac{1}{2}}+\nu_{o,1}^{\frac{3}{2}}\right)(1-\nu_{o,1}^2)^{-\frac{1}{2}}. \tag{15}$$

It has already been shown in Fig. 2 that the tube is imagined to be cut up into a number of identical zigzag paths. The attenuation of the tube is therefore the same as that of each path; accordingly (15) represents the attenuation constant of the whole tube for $H_{o,1}$ waves.

(4) *Attenuation for Waves of Higher Mode*

The result obtained for the principal wave may be extended most conveniently to waves of higher mode, i.e., $H_{o,m}$ waves, by inspection of Fig. 5, which represents the top of the tube for $m=3$. The dotted lines p, p′ and q, q′ indicate vertical planes along which the electric intensity is zero at all times and which divide the tube into m compartments or component tubes. Now imagine the right-hand side wall of the tube to be moved into the position p, p′, and consider for the moment the first compartment alone. The attenuation formula (15) can evidently be applied, the only modification required being to replace b by b/m and $\nu_{o,1}$ by $\nu_{o,m}$. If the side wall is now moved back into its original position and a flat-strip transmission line is considered stretching across the whole tube, i.e., from A to B, it is observed that the first term of the modified formula still holds, the attenuation of the line from A to B being the same as that from A to B[1]; but the interval between successive reflections is m times the interval for the first compartment, hence the second term of the modified formula is to be divided by m. Applying these modifications to (15) the attenuation constant for $H_{o,m}$ waves is obtained. Thus

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* The same expression is obtained when the wave advancing along the zigzag line is, at the vertex, regarded as falling upon a metal surface at which it is partly reflected and partly absorbed. The formulae appertaining to this mode of treatment are, for example, contained in a paper by Fry.[14]

$$\alpha_{H_{o,m}} = Kb^{-\frac{3}{2}} m^{\frac{1}{2}} \left(\frac{b}{2a} \nu_{o,m}^{-\frac{1}{2}} + \nu_{o,m}^{\frac{3}{2}} \right) (1 - \nu_{o,m}^2)^{-\frac{1}{2}}, \quad (16)$$

which agrees with the expression established by Chu and Barrow.[7] It is also in complete agreement with the expression furnished by Schelkunoff's general formula, for metal tubes of *any* shape, when that formula is applied to $H_{o,m}$ waves in rectangular tubes.[6]*

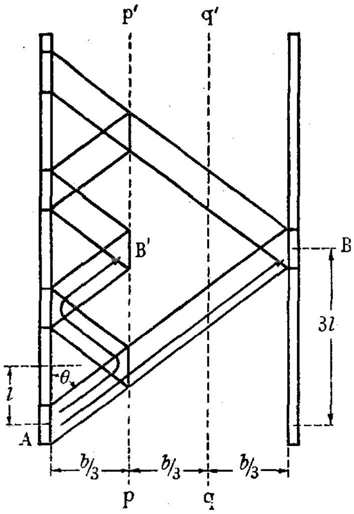

Fig. 5—System of Flat-Strip Transmission Lines for Waves of Higher Mode.

An alternative mode of splitting up the tube into a system of flat-strip transmission lines is seen in Fig. 6. In this case m sets of lines are set up, each set functioning independently of the others, separated from them by planes of zero electric intensity. In fact, the tube is considered as m component tubes, to each of which formula (15) is applicable directly if b is replaced by b/m and $\nu_{o,1}$ by $\nu_{o,m}$. For the first and last component tubes the term due to reflection losses is to be halved, as there are no losses along the interior planes of zero electric intensity. Similarly, for the interior component tubes, which are located entirely in the interior of the main tube, the second term in the formula vanishes. Thus, for the first and the last component tube the attenuation constant is

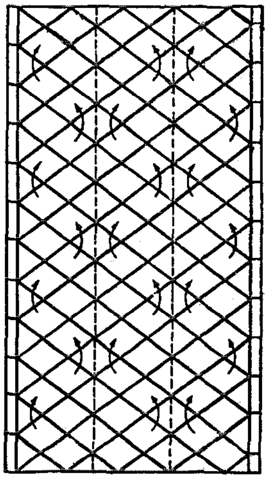

Fig. 6—Alternative System of Flat-Strip Transmission Lines for Waves for Higher Mode.

$$Kb^{-\frac{3}{2}} m^{\frac{3}{2}} \left(\frac{b}{2am} \nu_{o,m}^{-\frac{1}{2}} + \tfrac{1}{2} \nu_{o,m}^{\frac{3}{2}} \right) (1 - \nu_{o,m}^2)^{-\frac{1}{2}}, \quad (17)$$

while for the remaining m-2 tubes the attenuation constant is

$$Kb^{-\frac{3}{2}} m^{\frac{3}{2}} \frac{b}{2am} \nu_{o,m}^{-\frac{1}{2}} (1 - \nu_{o,m}^2)^{-\frac{1}{2}}, \quad (18)$$

and, on averaging (17) and (18), formula (16) is regained.

(5) *Losses in the Dielectric of the Tube*

So far it has been assumed that the dielectric of the tube is perfect. If the conductivity of the dielectric is small, yet not negligible, an allowance can be made by taking into account the second term of formula (3) for the attenuation constant. Substituting in this the values from (1), an additional term is obtained, viz.,

---

* Two formulae are given for the attenuation constant of H-waves. The first is general, for metal tubes of all shapes, and for waves of all orders; the second is derived from the first and appertains to tubes of rectangular cross-section only. This subsidiary formula is valid for waves of all orders other than zero. The need for separate treatment of zero-order waves arises from the fact that for these waves the electric intensities between the top and bottom of the tube are constant, while for waves of all other orders they vary sinusoidally. When losses are considered, mean-square values are required, and thus there emerges a factor $\frac{1}{2}$ for waves of all orders other than zero. An analogous position exists in respect of the losses due to the various harmonics of an alternating current and that due to a direct current, if the direct current is regarded as a harmonic of zero order.

$$\frac{G_1}{2}\sqrt{\frac{L_1}{C_1}}=\frac{\sigma_1}{2}\sqrt{\frac{\mu_1}{\kappa_1}}. \tag{19}$$

As the conductivity of a dielectric is usually expressed in terms of the loss angle δ, it is convenient to introduce into (19) the relation $\tan\delta=\sigma_1/(\omega\kappa_1)$ and, if allowance is made, as before, for the zigzagging of the line, the following expression is obtained for the adjustment due to the losses in the dielectric:

$$\frac{m\pi}{2b}\,\nu_{o,m}^{-1}(1-\nu_{o,m}^{2})^{-\frac{1}{2}}\tan\delta, \tag{20}$$

and this term must be added to the attenuation constant given by (16).

(6) *Conclusions*

The method reveals the existence of a link between two seemingly disjointed branches of telecommunication: (1) Telecommunication of the classical character, employing a "circuit," i.e., a system comprising a "go" and a "return" path, and (2) Telecommunication through hollow metal tubes without a return path in the conventional sense.

The final expression found in equation (16) for the attenuation constant of waves propagated through hollow metal tubes is derived in a simple manner from the familiar equations for the attenuation of telephone lines, with due regard to the reflection loss at the junction of dissimilar lines. The numerical results obtained by this shortened method agree in every respect with those obtained by more elaborate means by other investigators. The simplicity of the method and the ease with which the final results are obtained arise from the fact that the telephone transmission formulae contain implicitly the concepts required in the detailed calculation by orthodox procedure.

(7) *References*

1. LORD RAYLEIGH: "On the Passage of Electric Waves through Tubes, or the Vibrations of Dielectric Cylinders," *Philosophical Magazine*, 1897, **43**, p. 125.
2. G. C. SOUTHWORTH: "Hyper-frequency Wave Guides—General Considerations and Experimental Results," *Bell System Technical Journal*, 1936, **15**, p. 284.
3. J. R. CARSON, S. P. MEAD and S. A. SCHELKUNOFF: "Hyper-frequency Wave Guides—Mathematical Theory," *ibid.*, 1936, **15**, p. 310.
4. W. L. BARROW: "Transmission of Electromagnetic Waves in Hollow Tubes of Metal," *Proceedings of the Institute of Radio Engineers*, 1936, **24**, p. 1298.
5. L. BRILLOUIN: "Propagation of Electromagnetic Waves in Tubes," *Revue Génerale de l'Électricité*, 1936, **40**, p. 227.
6. S. A. SCHELKUNOFF: "Transmission Theory of Plane Electromagnetic Waves," *Proceedings of the Institute of Radio Engineers*, 1937, **25**, p. 1457.
7. L. J. CHU and W. L. BARROW: "Electromagnetic Waves in Hollow Metal Tubes of Rectangular Cross-Section," *ibid.*, 1938, **26**, p. 1520.
8. A. G. CLAVIER and V. ALTOVSKY: "Experimental Researches on the Propagation of Electromagnetic Waves in Dielectric (cylindrical) Guides," *Electrical Communication*, 1939, **18**, p. 81.
9. S. A. SCHELKUNOFF: "Electromagnetic Theory of Coaxial Transmission Lines and Cylindrical Shields," *Bell System Technical Journal*, 1934, **13**, p. 532.
10. L. PAGE and N. I. ADAMS: "Electromagnetic Waves in Conducting Tubes," *Physical Review*, 1937, **52**, p. 647.
11. S. A. SCHELKUNOFF: "The Impedance Concept," *Bell System Technical Journal*, 1938, **17**, p. 17.
12. A. G. CLAVIER: "Theoretical Relationships of Dielectric Guides (Cylindrical) and Coaxial Cables," *Electrical Communication*, 1939, **17**, p. 276.
13. G. W. O. HOWE: "The Application of Telephone Transmission Formulae to Skin-effect Problems," *Journal I.E.E.*, 1916, **54**, p. 473.
14. T. C. FRY: "Plane Waves of Light—Reflection and Refraction," *Journal of the Optical Society of America*, 1928, **16**, p. 1.

12-Channel Carrier Equipment in the Göteborg-Malmö Cable

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Introduction

SINCE the installation, in 1922/23, of the first small gauge, loaded and repeatered cable between Stockholm and Göteborg, the Swedish toll cable network, year by year, has been extended so that today it comprises a total of 5508 km of cable, covering the most important industrial and commercial sections of the country. Incidentally, the first Stockholm–Göteborg cable is now being de-loaded in order to adapt it to multi-channel telephone operation. In 1940, the latest link in the Swedish toll cable system was completed by joining the two cities of Göteborg and Malmö by a most up-to-date cable system. The distance involved is 277 km, and, since economic studies had shown that the through-circuits, at least, could most profitably be obtained by the use of 12-channel carrier circuits, two non-loaded cables were laid, side by side, throughout the whole distance.

From Göteborg to Helsingborg (217 km) each cable comprises 19 pairs of 1.2 mm conductors, whilst for the remaining 60 km, Helsingborg–Malmö, the two cables each contain 7 quads of 1 mm conductors. In order to cater for intermediate and branch traffic a third cable was installed along the same route and at the same time. This cable contains from 72 to 140 quads—as dictated by traffic considerations—of small gauge conductors, loaded to suit the particular transmission requirements of each case; it includes three intermediate repeater stations, which coincide with some of the stations necessary for the 12-channel cables. All three cables are armored and laid directly in the ground, covered only by a creosoted board.

Fig. 1 shows, graphically, the lay-out of the repeater stations along the route. The stations at Varberg, Halmstad and Helsingborg are those common to the 12-channel and the loaded cables.

Cable Specification

As a background to the overall transmission results, recorded further on, the main specification requirements of the cables intended for carrier operation are briefly given below. The figures apply to repeater sections and are valid for the frequency range 12,000–60,000 p/s.

The maximum attenuation shall be 0.168 neper/km (1.5 db) in the case of the cable of 1.2 mm conductors and 0.203 neper/km for the 1.0 mm conductors. The far-end crosstalk between pairs in the same cable shall be such that the difference in level at the far end between a disturbing and a disturbed pair shall be at least 8.5 nepers (74 db). The near-end crosstalk between pairs in the same cable shall not be less than 6.5 nepers (56 db) whilst, between

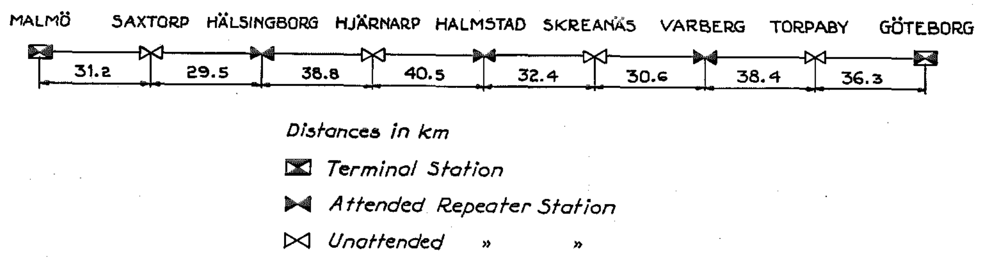

Fig. 1—Layout of Repeater Stations Along Cable Route.

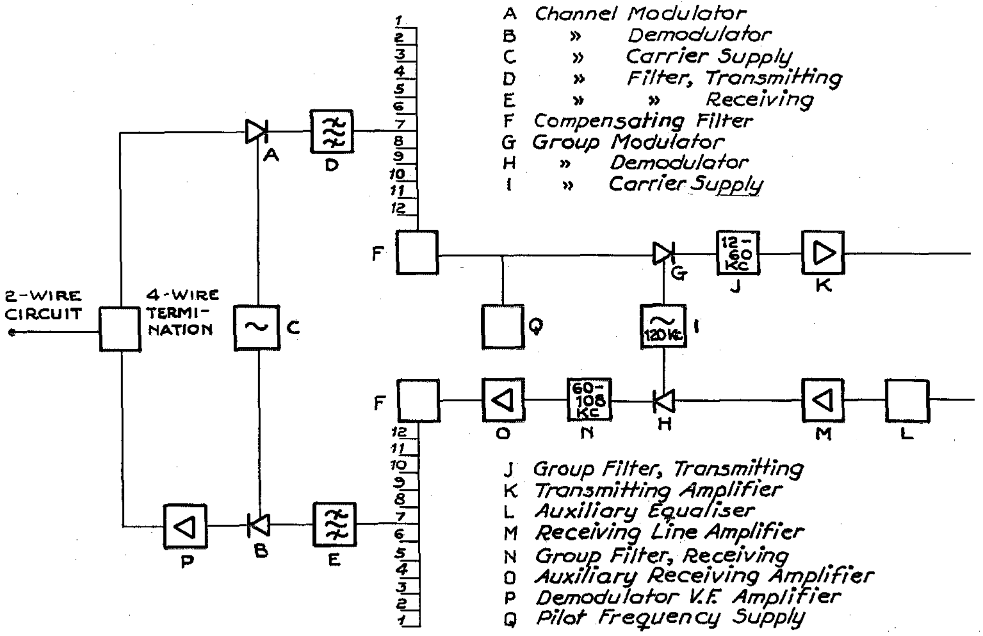
A Channel Modulator
B » Demodulator
C » Carrier Supply
D » Filter, Transmitting
E » » Receiving
F Compensating Filter
G Group Modulator
H » Demodulator
I » Carrier Supply
J Group Filter, Transmitting
K Transmitting Amplifier
L Auxiliary Equaliser
M Receiving Line Amplifier
N Group Filter, Receiving
O Auxiliary Receiving Amplifier
P Demodulator V.F. Amplifier
Q Pilot Frequency Supply
2-WIRE CIRCUIT
4-WIRE TERMINATION
12-60 KC
120 KC
60-108 KC
1
2
3
4
5
6
7
8
9
10
11
12

Fig. 2—General Transmission Features of Type K 12-Channel Carrier System.

pairs in separate cables, it must not be less than the cable attenuation plus 8.5 nepers.

The characteristic impedance Z_1 of an arbitrarily chosen pair shall not deviate from a nominal value Z_0 by more than an amount which satisfies the following relation:

$$\left|\frac{Z_0-Z_1}{Z_0+Z_1}\right| \leqq 0.025.$$

The nominal value of Z_0 was fixed by agreement between the cable contractor and the supplier of the repeater equipment.

Twelve-Channel Equipment

To meet the present demands of the through-traffic between Göteborg and Malmö, four Type K carrier equipments were installed, thus providing for a total of 48 circuits.

General Transmission Features

The general transmission features of the Type K system are indicated in the block schematic, Fig. 2. Voice frequencies, arriving from the toll board, pass through the 4-wire terminating set in the usual way. They are then modulated in the channel modulator, *A*, with carrier frequencies of 64, 68, 72, etc., to 108 kc/s, according to the particular channel in question. In the case of Channel 7, shown on the schematic, the channel carrier frequency is 84 kc/s. The lower sideband, resulting from this modulation, is selected by the modulator channel filter, *D*. This sideband, together with the eleven others, emanating from the remaining channels, passes through a compensating filter, *F*. All twelve sidebands, which now form a single group, occupying the frequency range, 60 to 108 kc/s, next pass through the group modulator, *G*, where they are modulated with a carrier frequency of 120 kc/s. The lower sideband, produced by this modulator, is chosen by the low-pass filter, *J*. This sideband now occupies the frequency range 12 to 60 kc/s, and is transmitted to the cable pair via the transmitting amplifier, *K*.

In the reverse direction, the line frequencies of

12 to 60 kc/s, corresponding to the twelve separate channels, pass as a group through the auxiliary equalizer, *L*, and the receiving line amplifier, *M*, which together compensate the attenuation and distortion produced by the cable pair. They then pass through the group demodulator, *H*, the carrier supply to which is 120 kc/s. The lower sideband produced by this demodulator lies in the range 60 to 108 kc/s. This is selected by the low-pass filter, *N*, and is stepped up to the required level by the auxiliary amplifier, *O*. It then passes via the compensating filter, *F*, to the paralleled inputs of the 12-channel demodulator filters. In the case of Channel 7 (Fig. 2), the filter, *E*, selects the frequency band 80 to 84 kc/s, which then passes through the channel demodulator, *B*. Here it is demodulated with the appropriate carrier frequency (84 kc/s in the case of Channel 7) and the sidebands produced pass on to the voice frequency amplifier, *P*. This amplifier transmits the lower sideband, 0 to 4 kc/s, and amplifies it to the appropriate level, but suppresses the unwanted sidebands. Thus the original speech frequencies are reproduced and pass on to the toll board via the 4-wire terminating set.

It will be seen from Fig. 2 that a pilot frequency supply, *Q*, is introduced at the input of the group modulator. This supply comprises three frequencies which, after passing through the group modulator, appear on the line as 15.9, 27.9 and 55.9 kc/s. These frequencies lie in the otherwise unoccupied regions of the transmitted frequency band, and their levels are accurately adjusted at the sending end to a known value. Thus, by the use of a highly selective level measuring set at any suitable point along the line—usually at the receiving end—transmission level measurements can be made at any time without interrupting any channel and without cooperation from the sending end. The three pilot frequencies lie well spaced over the transmitted frequency band and thus allow the equalization of the cable pair plus the line amplifier to be kept under constant observation.

SYSTEM FEATURES

The outstanding features of the constituents mentioned in the general description above are described somewhat more in detail below.

Modulators and Demodulators—The channel modulators and demodulators, *A* and *B* in Fig. 2, are of the bridge type and employ metallic rectifiers. The group modulators and demodulators, *G* and *H*, also employ such rectifiers, but they are of the double-balanced type, permitting a simplification of the associated filters.

Filters—The channel modulators and demodulator band-pass filters, *D* and *E*, are of the quartz crystal type; their schematic circuits are equivalent to two lattice sections. They are enclosed in hermetically sealed cans from which all traces of moisture have been removed. The group modulator and demodulator filters, *J* and *N*, are of the low-pass type and employ coils and condensers. This simple construction is possible because the unwanted modulation products are widely separated from the wanted lower sideband. Other filters are used in the carrier supply circuit and in the pilot supply circuit; they are of the quartz crystal type and are referred to later.

Amplifiers and Equalizers—The transmitting amplifier, *K*, is a three-stage, feed-back amplifier with a flat gain/frequency characteristic. The receiving line amplifier, *M*, is also a three-stage feed-back amplifier but it has a line equalizer in the feed-back circuit, producing a sloping gain/frequency characteristic. This corrects the major part of the distortion introduced by the cable pair. An auxiliary equalizer, *L*, is used to correct the small amounts of residual distortion. This is a constant resistance equalizer and is adjustable by means of soldered connections. The line amplifiers and auxiliary equalizers at the intermediate amplifier stations are of the same type as *L* and *M*, described above. The auxiliary receiving amplifier, *O*, is a two-stage feed-back amplifier with a flat gain/frequency characteristic. The demodulator amplifier, *P*, is a single-stage voice frequency amplifier with feed-back. It has a maximum gain of about 4 nepers (35 db), which can be continuously adjusted over a range of 1.15 nepers (10 db) by means of a rheostat in the feed-back circuit. It amplifies voice frequencies up to 4 kc/s, but suppresses higher frequencies, thus also performing the function of a low-pass filter.

Carrier Supply—A basic frequency of 4 kc/s is generated by a tuning fork in conjunction with a vacuum tube. This is amplified, first by a "control" tube and then by a push-pull amplifier, the output being about 4 watts. The output is filtered and applied to a circuit containing a non-linear inductance coil; this circuit produces odd harmonics of 4 kc/s. The odd harmonics required for the channel carrier frequencies are selected by crystal filters, from which they pass via adjustable resistances to bus-bars and thence through protective resistances to the channel modulators and demodulators as required. These odd harmonics are 8 kc apart; a simple crystal filter equivalent to a single lattice section suffices for their separation.

The even harmonics of 4 kc/s are produced in a separate branch, consisting of a metallic bridge-type rectifier, bridged across the output of the odd-harmonic producing coil circuit. The even harmonics thus appear at the output of the rectifier circuit; they are filtered and distributed in the same way as the odd harmonics.

The harmonic producing circuit has the property of creating all required harmonics at the same level, and sufficient power is available for the channel modulators and demodulators without subsequent amplification. Small adjustments to the voltages of the various channel carrier frequencies are made by the adjustable resistances referred to above.

The group carrier frequency of 120 kc/s is obtained via a two-section crystal filter from the even-harmonic branch of the circuit. Since a higher carrier voltage is required in the group modulators and demodulators than in the channel modulators, a single-stage amplifier is employed to produce the necessary power, which is then passed on to bus-bars and distributed to the various systems via protective resistances.

In order to guard against the multi-failure of channels, which would occur if the carrier supply (and more particularly the 120 kc/s supply) were to break down, the 4 kc oscillator and harmonic producing equipment are duplicated. Also, the 120 kc/s filter and amplifier are provided in duplicate, but not the channel carrier filters or distributing arrangements. There are thus two carrier generating equipments, the regular carrier generator and the emergency carrier generator. The load is normally carried by the regular generator, whilst the emergency one is in full working condition (tuning fork vibrating and valves heated) except for the fact that its control grid is blocked by a high negative bias, which persists as long as the 120 kc output from the regular generator is at a suitable voltage. If the 120 kc output falls below the desired value, a transfer circuit, described later, operates; the blocking voltage is removed from the emergency control tube and applied to the grid of the regular control tube, thus permitting the emergency carrier generator to take the load, blocking the regular generator. At the same time an alarm is given to indicate the change-over. The blocking voltage is produced in a carrier generator transfer circuit employing two gas-filled tubes (multipled for safety). These tubes are normally biassed by a voltage obtained by rectification from the 120 kc/s supply and is of such a value that no plate current flows. Associated with their plate circuits is a Wheatstone bridge type of network, which produces the blocking voltage for the emergency generator and the operating bias for the regular generator so long as no plate current flows. If the 120 kc/s voltage falls and reduces the bias on the gas-filled tubes below a certain point, space current flows and upsets the balance of the Wheatstone bridge with the result that the blocking and operating voltages are interchanged. Since the control is entirely electronic, the change-over is very rapid, i.e., in about 4 milliseconds. Relays are included in the transfer circuit for alarm purposes. Change-over can be effected for testing purposes by manually operated push buttons, which are also used to reset the circuit after it has operated.

The outputs of the regular and emergency generators are connected to the carrier supply filters via hybrid coils so that no switching is needed when changing over and, further, no interaction between the two generators occurs.

Synchronization of carrier frequencies is extremely simple, being effected by a small air condenser in the 4 kc tuning fork circuit. This, of course, simultaneously corrects all carriers produced by the carrier generators concerned.

Pilot Frequency Supply—A frequency of 3.9 kc/s is generated by a tuning fork oscillator and passed on to three bridge-type copper-oxide modulators, having carriers of 68, 96, and 108 kc/s, respectively, derived from the channel carrier bus-bars. The lower sideband frequencies, 64.1, 92.1 and 104.1 kc/s, are selected by crystal filters (identical with the carrier supply filters), the outputs of which are connected via individual rheostats to bus-bars, and thence via protective resistances to the group modulator inputs of the different systems. After passing through the group modulator, the pilot frequencies appear on the line as 15.9, 27.9 and 55.9 kc/s. The rheostats referred to enable the pilot levels, sent to the line, to be accurately adjusted.

Four-wire Terminating Sets—The 4-wire terminating sets are of the familiar type. Plug-in pads are provided on the transmitting side to adjust the voice-frequency input to the channel modulator to a level of −1.5 neper (−13 db). On the receiving side the demodulator amplifier delivers a level of +0.4 neper (+3.5 db), and plug-in pads are provided to reduce this to a value suited to the circuit concerned.

Maintenance Instruments—A mains-operated heterodyne oscillator, Type 17-B, is provided, covering the frequency range 25 p/s to 150 kc/s. An interesting feature of this instrument is the very open frequency scale, obtained by gearing the variable condenser up to drive a cinema-film scale, 7.6 metres long. Built-in calibrating circuits are provided, and the oscillator can be adjusted to any frequency within its range with an accuracy of 25 cycles. Between 1 kc and 150 kc the output is constant within 0.1 neper (0.9 db).

A No. 30-A Transmission Measuring Set is provided for measuring gains and losses. This set is portable and employs a thermocouple circuit with the galvanometer scale calibrated in decibels so that it is direct-reading. A variable attenuator forms part of the instrument together with patching and switching arrangements, also self-contained calibrating arrangements. All the components are brought out to jacks, rendering the operation of the instrument very flexible.

For measuring transmission levels at carrier frequencies, and more particularly for measuring pilot levels, the No. 42-A Transmission Measuring System is provided. The frequency to be measured is applied, via a high impedance pad, to the input of a copper-oxide modulator, the carrier frequency supply to which is obtained from the No. 17-B oscillator. The frequency of the heterodyne oscillator is adjusted to modulate the test frequency to 130 kc/s, this frequency being selected by a 130 kc crystal filter, passing a band confined to about ten cycles. The filtered 130 kc/s is amplified by a feed-back test amplifier and applied to a second modulator, where it is heterodyned with a 129 kc/s carrier, obtained from a crystal-controlled oscillator.

The 1 kc/s output of this modulator is amplified by a tuned 1 kc amplifier and passed on to the No. 30-A Measuring Set and there measured. A special calibrating oscillator with an accurately adjusted output is used to calibrate the system at a frequency in the middle of the carrier range. The bridging loss of the measuring system is less than 0.01 neper (0.1 db); levels of −2.7 nepers (−23.5 db) below 1 milliwatt can be measured without additional amplification. Arrangements can be made to measure lower levels if desired, and, as all the components are brought out to jacks, the circuit can be modified and used for special investigation work, if necessary. Owing to the very high selectivity of the set, such tests as carrier leak measurements and pilot level measurements can be made at any time without interrupting the service in any way. Measurement of carrier frequency levels on any channel can be accomplished without disturbing the other channels.

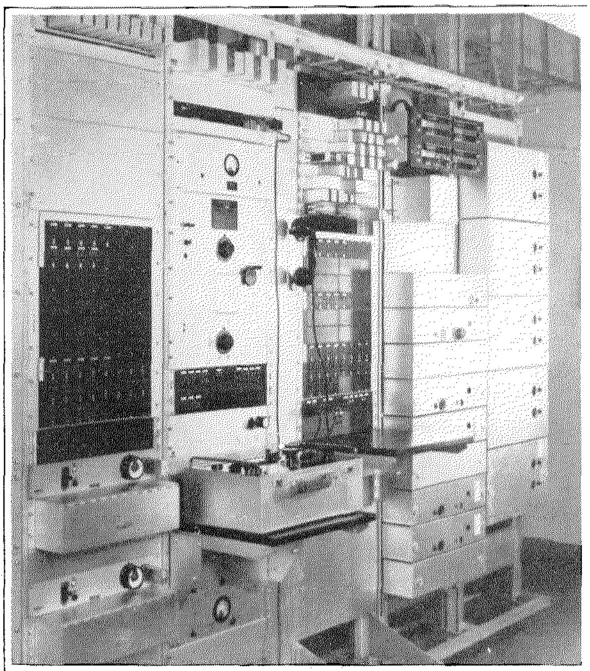

Fig. 3—Göteborg Terminal Equipment, Showing Communication, Measuring and Power Supply Bays.

Alarm Circuits and Telephone Circuits between Stations—One cable pair is used to transmit alarm signals from an unattended repeater station. It also serves as a telephone circuit to the unattended station. This pair is equipped with filters to suppress carrier noise, which might otherwise be introduced into the cable pair via the batteries and alarm or telephone equipment. It was originally intended to operate the alarm circuit with current normally on the line. It was found, however, quite satisfactory to have current on the line during the alarm period only, and the circuit was modified accordingly. The change enabled a 40-volt dry cell battery to be used for alarm purposes.

Grouping of Equipment

Channel Modem Panels—The channel modulators and demodulators (*A* and *B*, Fig. 2), the crystal filters, *D* and *E*, and the voice frequency amplifier, *P*, together with associated pads, resistances, etc., not shown on the block schematic, are mounted on a panel known as the Channel Modem Panel. One such panel mounts equipment for two channels. These panels are mounted in groups of six, corresponding to one system, and, associated with each group, is a panel mounting the compensating filters, *F*.

Group Modem Panels—The group modulator and demodulator, *G* and *H*, the filters, *J* and *N*, and the auxiliary amplifiers, *K* and *O*, are mounted together on a panel known as the Group Modem Panel. One such panel caters for a complete system.

Carrier Supply and Distribution Panels—The regular carrier oscillator together with the harmonic producing equipment, 120 kc/s amplifier and 120 kc/s filter are mounted on one panel. An exactly similar panel is provided for the emergency generator equipment. The pilot oscillator and modulator equipment together with the pilot distributing bus-bars and resistances are mounted as a panel. The transfer circuit forms a separate panel; separate panels are also provided for filters and distributing bus-bars and resistances for the odd and even channel carrier frequencies, and for the distributing bus-bars for the 120 kc/s group carrier frequency. These panels occupy two bays and cater for ten systems.

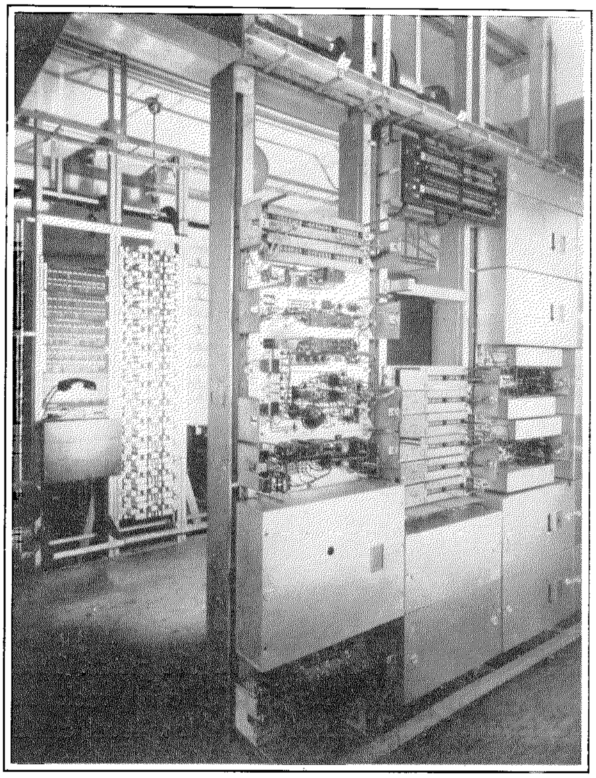

Fig. 4—Göteborg Terminal Equipment, Showing Carrier Supply and Distribution.

Line Amplifier and Equalizer Panels—The line amplifier, *M*, and the equalizer, *L*, are mounted on separate panels. Each line amplifier occupies one panel, whilst there are two equalizers per panel. Duplicate panels mount grid batteries for the line amplifiers and "Sensitrol" relays, respectively. The latter give an alarm if the grid battery voltage falls below a certain value. These panels also mount testing circuits for the grid batteries.

Jack Panels—All high frequency, high level jacks are mounted together on one panel, and all high frequency, low level jacks on another. These panels are well separated to avoid the possibility of crosstalk between them. A voice frequency jack panel, including monitoring jacks, is provided. This gives access to the voice frequency sides of the channels. Associated with these jacks are the gain-control rheostats for the channel demodulator amplifiers (*M*, Fig. 2). On the same bay as this jack panel is a vacuum tube monitoring panel as well as facilities for talking and ringing.

Testing Equipment—One bay mounts the 17-B heterodyne oscillator and the various other components of the No. 42-A Transmission Measuring System, not including the high frequency test amplifier which is mounted with the line amplifiers. Individual panels are cabled to a jack panel, mounted on the same bay. The No. 30-A Transmission Measuring Set, which is portable, is normally accommodated on a writing shelf on this bay, being connected to the jack field as required by a patching cord.

Four-wire Terminating Sets—The 4-wire terminating sets, together with their plug-in pads, are mounted on panels, there being two sets per panel.

Cabling Arrangements

High and low level carrier frequency cables are carefully segregated. In general, the high level cables are brought down one side of a bay, and the low level cables down the other. This segregation is maintained on the cable racks in the form of a high level and a low level cable group. Specially designed rubber insulated cables of a single screened pair are used for the high frequency transmission path. This type of cable has about the same iterative impedance as the main cable pairs, and long lengths of it can be used without introducing impedance irregularities. The earthing of the screens is given special attention.

Vacuum Tubes

With the exception of a few special tubes used in the No. 17-B oscillator, and the gas-filled tubes in the carrier generators, only two types of tube, the No. 310-A and the No. 311-A, are used in the whole system.

Terminal Equipment

Figs. 3 and 4 show views of the Göteborg terminal equipment. In Fig. 3, the first bay on the left contains the high frequency jacks and the grid-bias and alarm panels for the line amplifiers. On the second bay is mounted the No. 42-A Transmission Measuring Equipment with the No. 30-A Measuring Set on the writing shelf. On the third bay is the second high frequency jack panel, together with alarm equipment and telephone set for communication with the intermediate stations. The following, or fourth, bay mounts battery supply equipment, as well as receiving line amplifiers and auxiliary equalizers. The top amplifier panel on this bay is the test amplifier, forming part of the No. 42-A Measuring System. The bay on the extreme right mounts five group modem panels, the fifth panel being spare.

In Fig. 4, the first two bays on the left of the front rack mount the carrier supply and distribution equipment. The third bay mounts the 6-channel modem panels and compensating filters for one system. (Can covers of several panels are removed to show detail mounting arrangements.)

The rear rack contains, on the left, the voice frequency jacks and monitoring arrangements, and, on the right, the 4-wire terminating sets.

Overall Results

The overall equivalent of a representative system between Göteborg and Malmö is shown

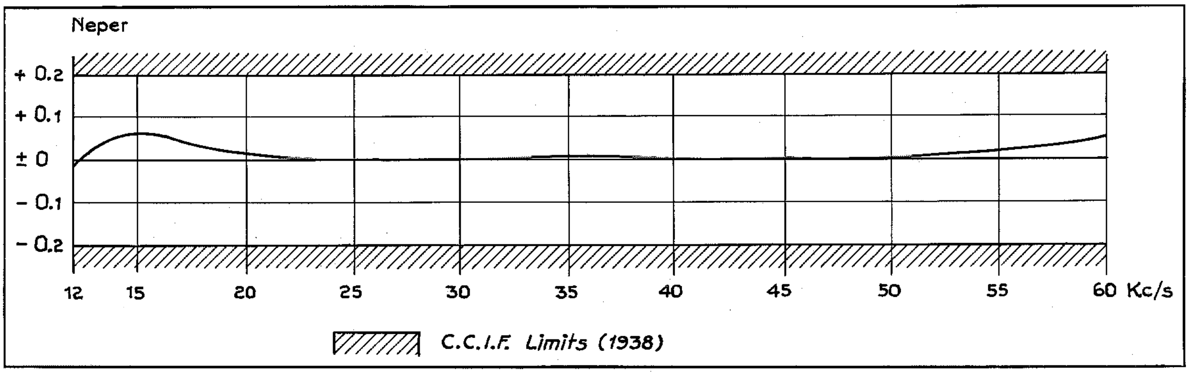

Fig. 5—Overall Equivalent of System No. 4 Göteborg—Malmö.

in the graph of Fig. 5. It will be noted that the curve falls well within the limits set by the last Assembly of the C. C. I. F. (1938).

As indicated in Fig. 6, the frequency range of one channel between Malmö and Göteborg is 160 to 3600 p/s. With five channels in tandem, the band 200–3300 p/s is transmitted.

The carrier circuits were placed in service in May, 1941.

The above-described equipment was manufactured by the Western Electric Company and supplied to the Swedish Telegraph Administration by Standard Telefon og Kabelfabrik A/S, Oslo.

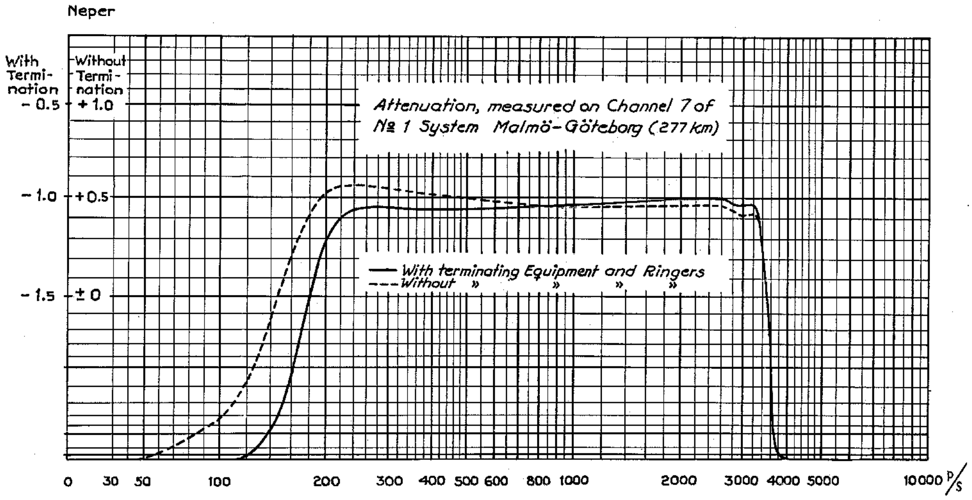

Fig. 6

Bibliography

1. "Carrier in Cable," by A. B. Clark and B. W. Kendall, *A.I.E.E. Transactions*, 1933, p. 1050; *B.S.T.J.*, July, 1933.
2. "Wide Band Transmission Over Balanced Circuits," by A. B. Clark, *A.I.E.E. Transactions*, 1935, p. 27; *B.S.T.J.*, Jan., 1935; *Electrical Communication*, Vol. 13, No. 4, 1935.
3. "Modern Systems of Multi-Channel Telephony on Cables," by A. S. Angwin and R. A. Mack, *Journal of I.E.E.*, April, 1937.
4. "Bristol-Plymouth 12-Channel Carrier System," *Electrical Communcation*, Vol. 16, No. 2, 1937.
5. "A Carrier Telephone System for Toll Cables," by C. W. Green and E. I. Green, *A.I.E.E. Transactions*, 1938, p. 227; *B.S.T.J.*, Jan., 1938.
6. "Cable Carrier Telephone Terminals," by R. W. Chesnut, L. M. Ilgenfritz and A. Kenner, *A.I.E.E. Transactions*, 1938, p. 237; *B.S.T.J.*, Jan., 1938.
7. "Crystal Channel Filters for the Cable Carrier System," by C. E. Lane, *A.I.E.E. Transactions*, 1938, p. 245; *B.S.T.J.*, Jan., 1938.
8. "Crosstalk and Noise Features of Cable Carrier Telephone System," by M. A. Weaver, R. S. Tucker and P. S. Darnell, *A.I.E.E. Transactions*, 1938, p. 250; *B.S.T.J.*, Jan., 1938.
9. "Copper Oxide Modulators in Carrier Telephone Systems," by R. S. Caruthers, *B.S.T.J.*, April, 1939.
10. "Load-Rating Theory for Multi-Channel Amplifiers," by B. D. Holbrook and J. T. Dixon, *A.I.E.E. Transactions*, 1940, p. 265.
11. "The Transmission Characteristics of Toll Telephone Cables at Carrier Frequencies," by C. M. Hebbert, *B.S.T.J.*, July, 1941.

Alarm and Control Systems—Banco de la Provincia de Buenos Aires

By W. WHITE

Compañía Standard Electric Argentina, Buenos Aires, Argentina

THE recently completed building of the Banco de la Provincia de Buenos Aires offers a fine example of modern banking architecture. Equipment installations embody the latest advances, including alarm and control systems, air conditioning and moving stairways.

Requirements for the signaling and control equipment were formulated in accordance with equally up-to-date standards. The system proposed by Compañía Standard Electric Argentina, Buenos Aires, met with the approval of the banking authorities and was installed. A view of the main control panel is shown in Fig. 1.

Watchman's Control System

This equipment is intended to control the movements of individual watchmen, three in all; their routes, together with time intervals between stations, are predetermined. Plans of the building appear on glass panels on which visual signals indicate the station next to be visited by a particular watchman. If, within the allotted interval, a watchman either fails to follow the prescribed route or to operate his special key at each station, an alarm is sounded and a lamp indicates the station involved. Normal movements of each watchman also are indicated on individual time charts (Fig. 2).

Watchmen's stations consist of double contact switching devices enclosed in sealed metal cases. They can only be operated by the special keys carried by the watchmen.

The central equipment has a capacity of sixty stations and three alarm groups. A separate alarm circuit is provided for each watchman.

Each alarm group comprises control relays and two step-by-step switches; one of these switches moves as a result of the turning of the watchman's key at the station, whilst the other advances through impulses from a master clock. Flexible connections between these two switches allow any time interval from one to twenty-five minutes in one-minute intervals to be allotted to any station. For the time chart record, each alarm group is provided with an Esterline Angus time register for twenty circuits, i.e., the number of stations assigned to each alarm group. This register, when operated, indicates the station signaling and the reception time of the signal.

The visual indication being a lamp, a routiner circuit is incorporated in the system in order to check the functioning of all lamps prior to a watchman commencing his rounds. Operation of the routiner key and the alarm test key corresponding to any single group causes the routiner to make a complete round of all the lamp circuits involved. This test is accomplished rapidly; a faulty lamp results in stoppage of the routiner at the corresponding point.

In the event of an alarm caused by delayed arrival at a station, a bell is sounded and the lamp of the station to which the watchman is proceeding remains lighted in order that an investigation may be made. Insertion of the key at the station restores the system to normal functioning except that the audible alarm is not silenced until the reset key on the central panel is operated. The period of delay during which the alarm is sounded is indicated by the time register on the watchman's chart.

The time register is driven by an eight-day spring mechanism and is provided with internal illumination to facilitate observation of the chart.

Faults, such as line failures and open circuits, result in an audible alarm which can be converted into a visual signal by depressing the fault alarm key. The visual signal remains lit until the fault is cleared.

General Alarm

For the general alarm service, "break-the-glass" push buttons function in association with a central alarm equipment comprising alarm relays operating visual and audible alarms as well as a chart time record. The audible signal provided for alarms on the operation of a push button is a 20 cm 24 volt bell.

Both the central equipment and the Esterline

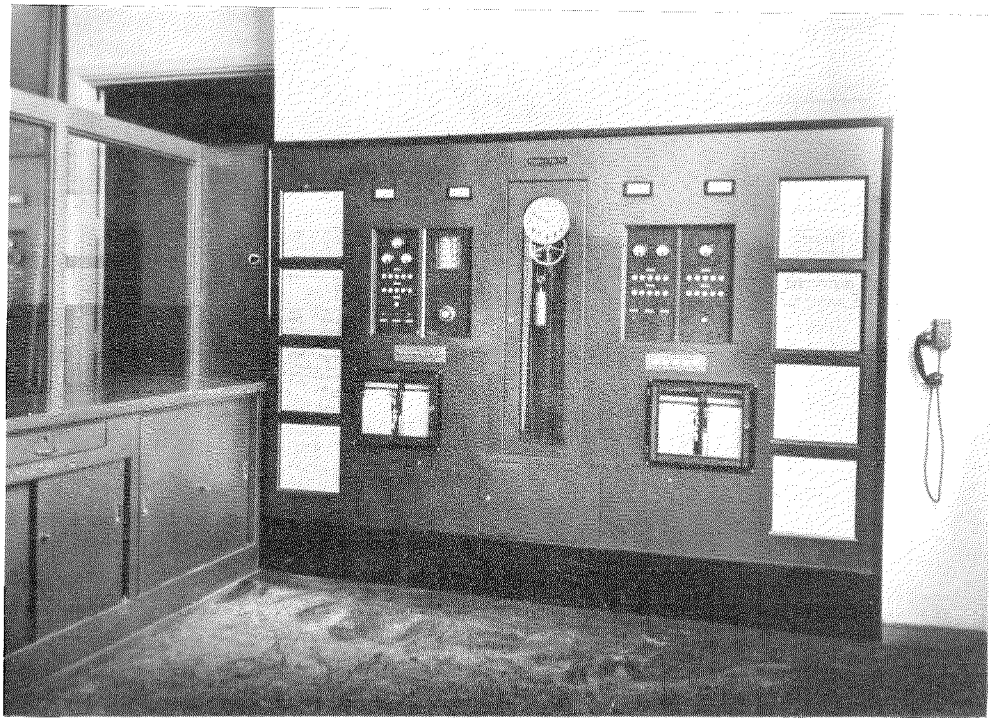

Fig. 1—Main Control Panel.

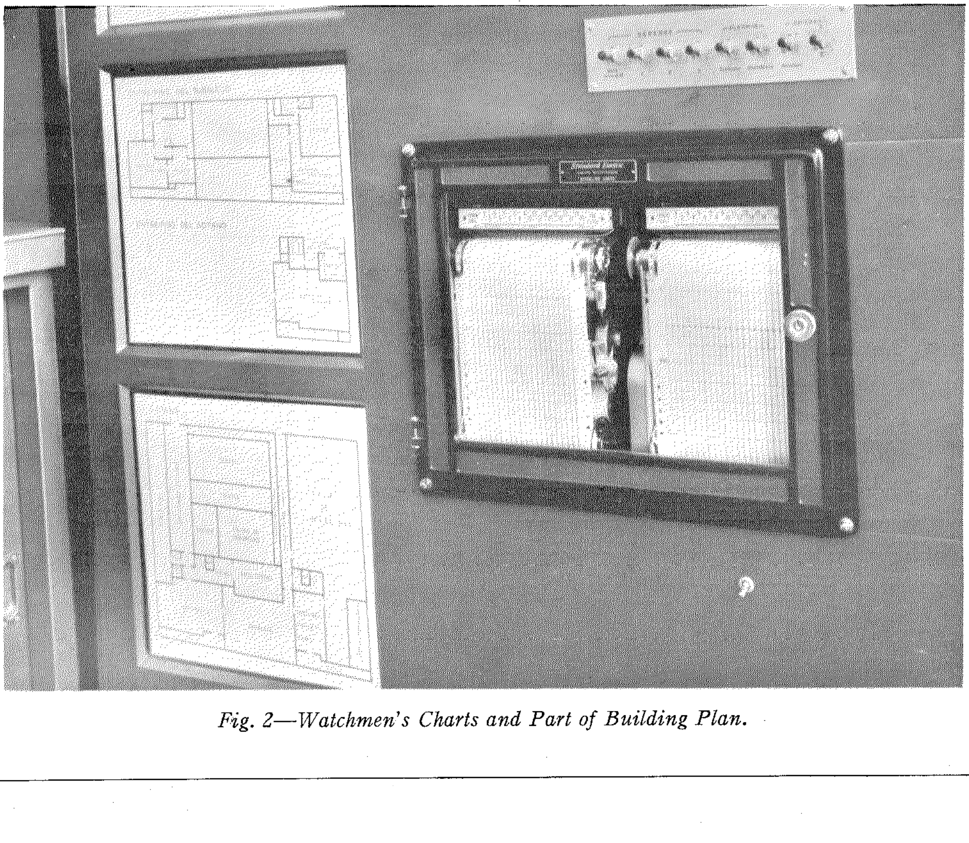

Fig. 2—Watchmen's Charts and Part of Building Plan.

Angus time register are designed for a capacity of sixty circuits; the present equipment consists of forty circuits.

Operation of a push button causes locking of the corresponding apparatus and recording of the alarm. To reestablish the circuit, the common reset key comprised in the central equipment must be operated.

The central equipment includes glass panels which individually represent one or two floors of the building in plan. On operation of an alarm push button, a red disc appears on the building plan indicating the point of origin of the alarm. Thus, time ordinarily lost in translating numbered lamps into actual building locations is eliminated.

The routiner used for checking the watchman's control system also serves for testing the lamps of the general alarm system; the two operations, in fact, are accomplished simultaneously, but the routiner includes two distinct circuits so that the specific failure is definitely indicated in all cases.

Fire Alarms

The thermostatic device employed for indicating room temperature rise above a predetermined level is adjustable over a wide temperature range by means of a micrometric screw and a calibrated disc. Operation of a thermostat produces an audible and a visual alarm at the central equipment.

Cashier Alarm

The cashier alarm is designed both for audible and visual alarms through the operation of foot pedals or paper sealed push buttons. When an alarm is given, a lamp indicates the circuit involved and a general audible alarm is sounded.

Strong Room Alarm

The equipment provided for each of the strong room doors consists of a delicately poised pendulum which rests on a three point contact. The pendulums are adjustable and are arranged to respond to any slight vibration of the doors to which they are fitted and thus to alter the circuit conditions of the system.

The equipment is designed to give an audible and visual alarm in the event of tampering with the strong room doors. Suitable precautions were taken against the possibility that the system might be rendered inoperative through the injection of liquid air which would freeze the delicate contacts of the pendulum mechanism and permit motion without disturbing the electrical circuit.

Pendulum mechanisms are connected to a central equipment providing individual visual and audible alarms in association with each pendulum. The central equipment is enclosed in a special case which, after the starting key is thrown and the door closed, cannot be opened in advance of a predetermined time without giving an alarm. For emergency conditions, however, access to the cut-off switches to each of the strong room alarms may be obtained through an additional door which can be opened by a changeable code lock.

The flexible cord connection to the pendulum is such that any attempt at short circuiting, cutting of conductors, etc., immediately results in an alarm.

Personnel Calling System

The installation includes a system of lamp indicating panels for paging executives.

Power Supply

The alarm and control system herein described is operated on the constant current principle designed to indicate faults such as opens, short circuits or ground. Two separate 24 V batteries, providing reserve in case of mains failure, are fed from a 220 V a-c source converted to d-c by means of a rectifier. Batteries are operated full float and are kept fully charged. A visual signal and an audible alarm, respectively, are given in case of mains supply or local battery failure.

Directory Information Bureau—Shanghai

By MISS L. A. E. MANN

Service Superintendent, Traffic Department, Shanghai Telephone Company

This article gives an outline of the development and operation of the bi-lingual Centralised Directory Information Bureau in Shanghai and indicates some unusual problems encountered in the operation of the Bureau.

1. *Introduction*

Shanghai is divided into three areas:

a) The International Settlement, comprising an area of approximately 8.75 square miles with a population of about 72,000 foreigners (non-Chinese) and 2½ million Chinese. Contiguous to the International Settlement are two zones known as "'Extra Settlement' or 'Outside Roads' Areas."

b) The French Concession, covering an area of approximately 3.94 square miles with a population of about 35,000 foreigners and about 1½ million Chinese.

c) Greater Shanghai, comprising the adjacent areas of Chapei, Civic Centre, Nantao and Pootung.

The Shanghai Company provides telephone service in the first two areas mentioned, including portions of the Outside Roads Area. Another Company, the Central China Telecommunications Company, furnishes service for greater Shanghai, intercommunication facilities between the two systems being provided.

Prior to 1930, when the Shanghai Mutual Telephone Company was merged into the International Telephone and Telegraph System as the 'Shanghai Telephone Company,' operation was largely on a local battery basis. A description of the conversion to automatic operation has been published.[1] The Shanghai Telephone Company now has in operation one common battery and seven full automatic central offices of the No. 7-A Rotary type, approximately 60,100 exchange lines and 93,400 stations being connected to the system at the end of August, 1941.

Shanghai is an extremely cosmopolitan city with nationals of almost every country in the world residing within its confines and, consequently, a great variety of languages is spoken. The two principal languages—those in which the Shanghai Telephone Company contracts to give service to its subscribers—are Chinese and English.

2. *History of the Information Bureau*

Just over ten years ago, each central office had its own 'enquiry' bureau, maintained its own set of information records covering the entire system, and dealt with all 'enquiries' originated by subscribers connected to that particular office. In each office three types of records were maintained, consisting of complete lists of subscribers in alphabetical (name), street and numerical (telephone number) order. The English and Chinese Alphabetical records comprised specially bound copies of the current directories with alternate sheets of blank paper on which amendments were recorded in manuscript facing the position they would occupy if printed in the standard copy, disconnections being crossed out on the printed pages. The Numerical and Street records, in English only, were contained in drawer files and gave the same information as the alphabetical records but in telephone number and street order respectively. To obtain access to the 'Enquiry' operators, foreign (non-Chinese) subscribers were instructed to call '499' and Chinese subscribers '599.' The majority of calls, however, were received via '499,' possibly because it was a much better known number since it had been in existence almost as long as the Telephone Company, and because many Chinese seemed to prefer dealing with the 'foreign' bureau.

At the beginning of 1930, in anticipation of the conversion to automatic, the 'Enquiry' service was centralised. Several of the existing English and Chinese Alphabetical records and one set of

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[1] "The Reconstruction of the Shanghai Telephone System," J. Haynes Wilson, *Electrical Communication*, July, 1932.

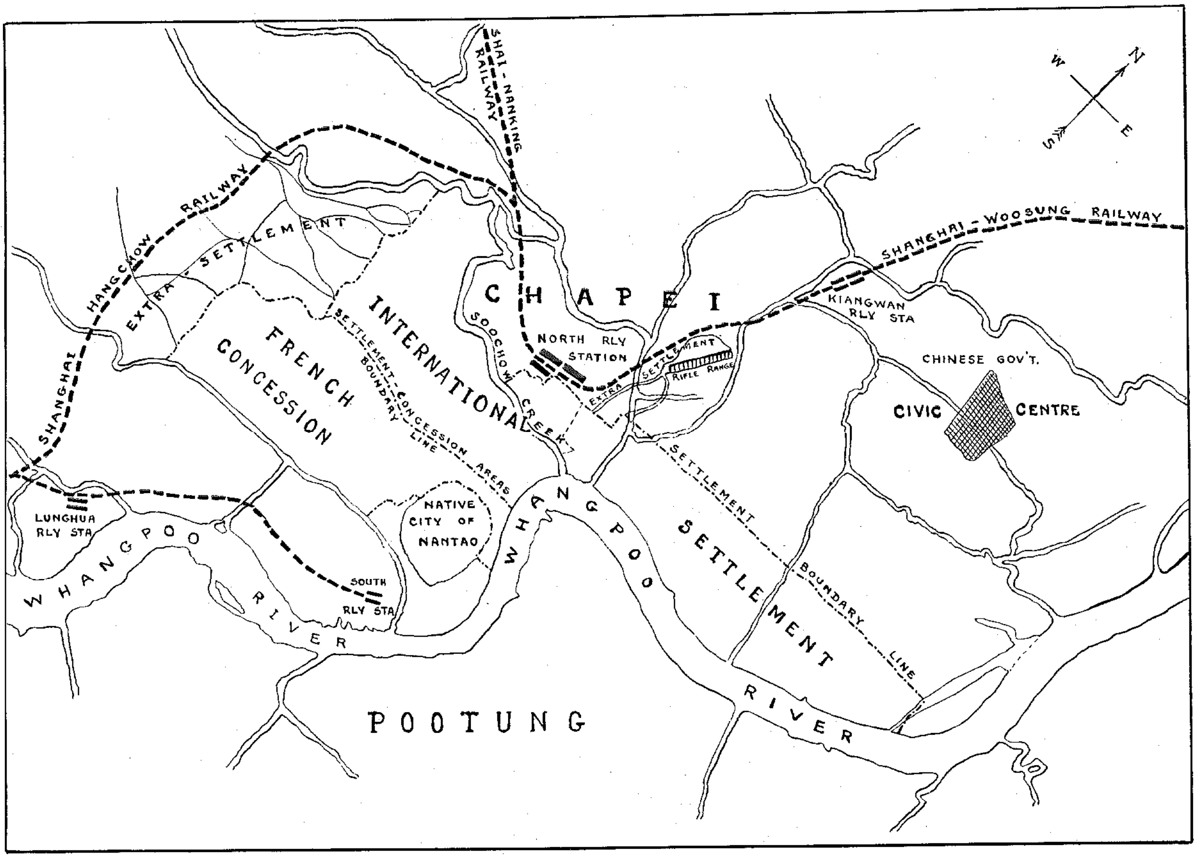

SHAI-NANKING RAILWAY
N
E
S
W
SHANGHAI-WOOSUNG RAILWAY
SHANGHAI-HANGCHOW RAILWAY
EXTRA SETTLEMENT
CHAPEI
NORTH RLY STATION
KIANGWAN RLY STA
CHINESE GOV'T. CIVIC CENTRE
INTERNATIONAL
SOOCHOW CREEK
FRENCH CONCESSION
SETTLEMENT-CONCESSION BOUNDARY LINE
EXTRA SETTLEMENT
RIFLE RANGE
SETTLEMENT AREAS
NATIVE CITY OF NANTAO
LUNGHUA RLY STA
WHANGPOO RIVER
SOUTH RLY STA
WHANGPOO
SETTLEMENT
SETTLEMENT BOUNDARY LINE
RIVER
POOTUNG

Fig. 1—Sketch Map of Shanghai.

Street records were utilised, while a new Numerical file was developed. This contained one card for each central office line, the cards being approximately 3½ by 2½ inches in size and filed in open steel trays on a special table which, together with the Street records, was located a few feet behind the suite of operating desks. Since it was not practicable to have the operators leave their positions to refer to these records, a number of 'small boy' messengers were provided. Thus, a subscriber wishing to make an 'enquiry' called '499,' where the call was transferred to the centralised 'Enquiry' operators. If the enquiry was of an alphabetical nature, that is, if the caller required the telephone number for a particular name, the operator furnished it by direct reference to one of the special directories. If, however, the caller required the name of the subscriber owning a specified telephone number, or the telephone number of a certain address, the operator requested a 'small boy' to procure the appropriate card or tray, from which the required information was obtained and relayed to the caller, the card or tray thereafter being returned to its proper place by the 'small boy.'

This operating procedure was a definite advance on the previous decentralised scheme, but with the conversion of the system to automatic operation it was necessary to provide a more rapid and less cumbersome method of dealing with information calls. It was therefore decided to provide one centralised information bureau to serve the entire city and to adopt the rotary file type of information records, so that the receiving operator could give the required information direct to the caller.

A rotary file, as the name suggests, consists of a drum which is mounted on a vertical axis around which it can be rotated in either direction. Each drum contains a number of varying size and capacity frames which can easily be removed from the drum as required, the number of such frames on each drum depending on local requirements. Drums can be mounted singly or one above the other but operating independently. Each of the drums used in the Shantelco C.I.B. contains 450 frames, each of which is 6 inches wide by $12\frac{1}{8}$ inches high. Moveable index tabs are associated with each frame so that adequate indexing can be provided to facilitate reference. The directory information is recorded on flexoline strips, usually referred to as inserts; these inserts are supplied in sheet form and in suitable widths for various sized frames, each insert being 'scored' so that it can be easily detached. Hence it is possible to file the inserts in any order required, and amendments, deletions or additions can be quickly effected. The sheets of flexoline inserts used by Shantelco measure 6 inches in width and contain 42 inserts per sheet.

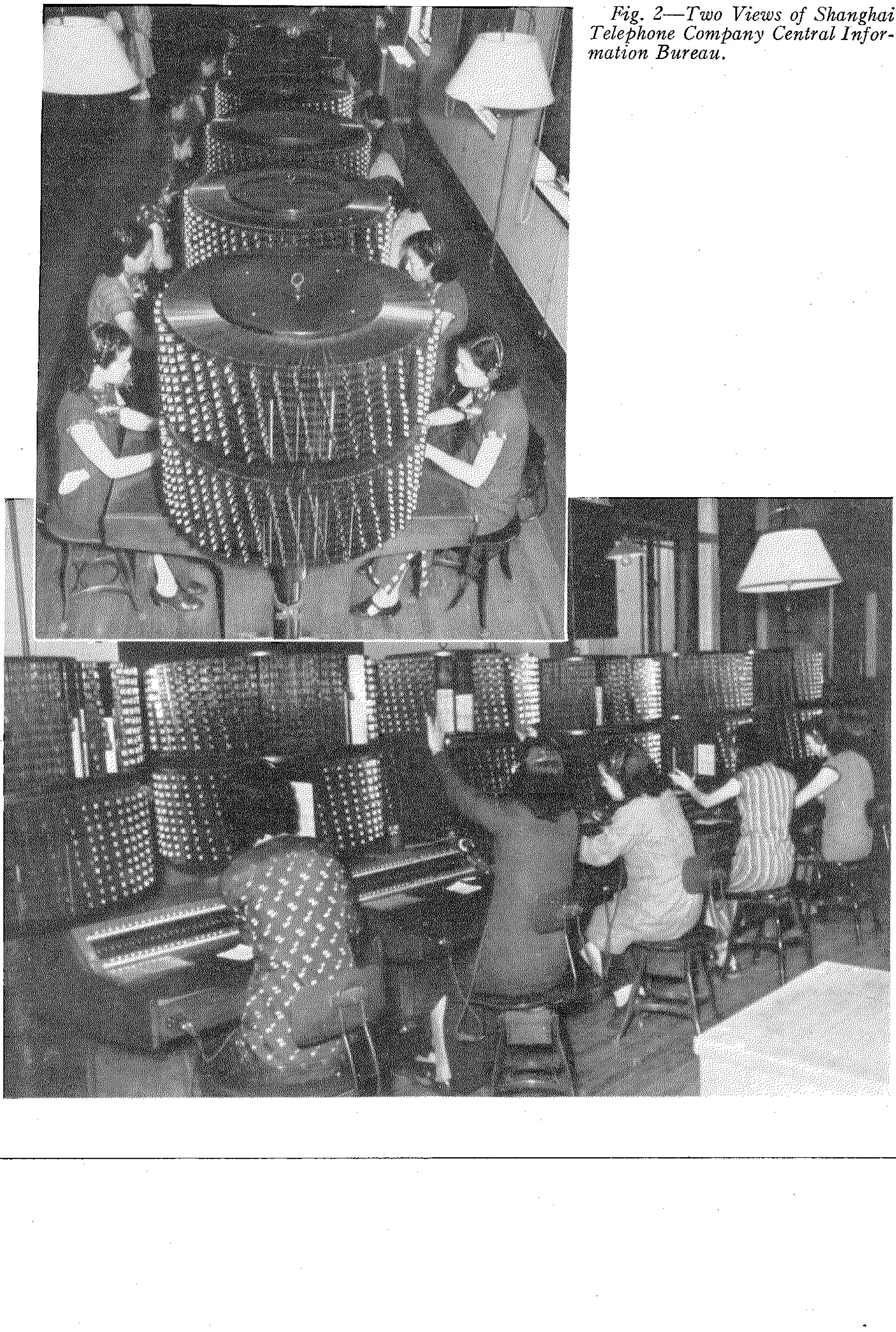


Fig. 2—Two Views of Shanghai Telephone Company Central Information Bureau.

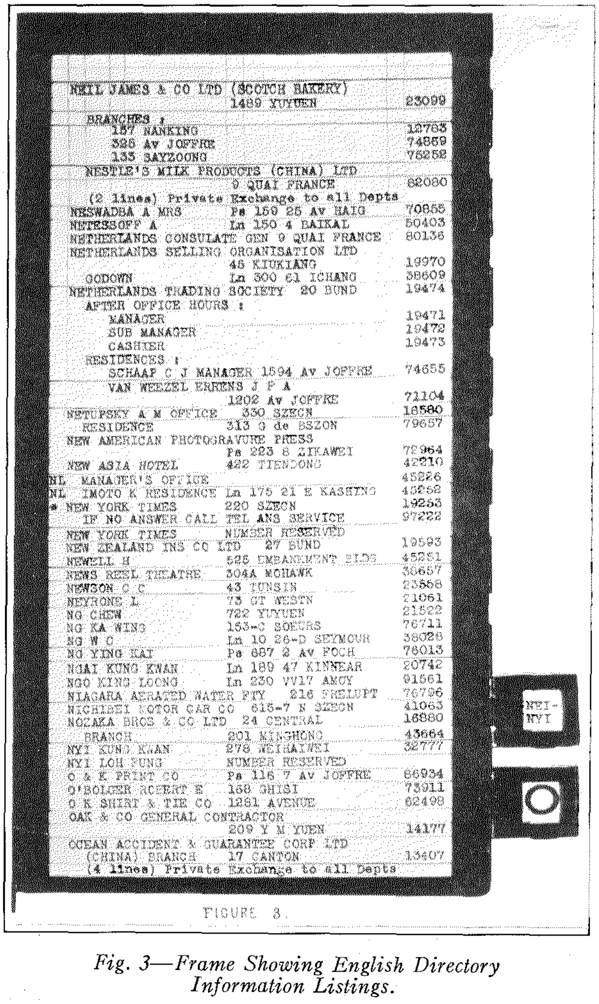
In September, 1931, the present C.I.B. was brought into operation, '09' being allocated as the 'Information' number. Until March, 1932, when the conversion of the system to automatic operation was completed, both information bureaus functioned, the old one continuing to take care of 'enquiries' from manual subscribers via '499,' whilst the new one handled 'information' calls from automatic subscribers via '09.' In the new C.I.B., the location of the information records was such that each operator had easy access to all records. English Alphabetical, Street and Numerical information was furnished from rotary files, whilst Chinese Alphabetical information was still supplied from the special interleaved directories. Towards the end of 1932 the increase in the number of information calls from Chinese subscribers, and the difficulty of accurately maintaining the special directories, necessitated the development of some other form of Chinese alphabetical reference; Chinese alphabetical rotary files accordingly were brought into operation early in 1933.

Considerable difficulty was encountered during the planning of these files due to the fact that no 'Chinese Character' typewriting machines could be found to type the flexoline inserts satisfactorily; the only suitable alternative was to 'write' the inserts, and this method was finally adopted and has proved satisfactory in all respects. While the Chinese language is usually read from top to bottom of a page and from right to left, the C.I.B. Chinese files follow the same layout as the English files, that is, with the name on the left, the address in the centre and the telephone number on the right, the latter being shown in romanised figures.

With the development of the system and the consequently increasing demands upon the C.I.B., it became necessary in the interests of economic operation to cease supplying Numerical and Street information, since the continuance of these facilities would have necessitated an increase in the number of C.I.B. operating positions and the purchase of additional rotary files. Furnishing Numerical information was therefore discontinued in December, 1932, and Street information in June, 1934. However, arrangements were made with the Plant Department for supplying the Fire and Police Departments of the International Settlement and French Concession with information concerning the name and address of a specified telephone number.

Although Street information is no longer supplied to subscribers, in cases where the caller states that the matter is of great urgency, reference is made by the C.I.B. forces to the 'China Hong List' which includes a certain amount of street information. Any information contained therein is given to the caller with a statement as to its source.

The C.I.B. at present consists of five double-sided desks comprising ten operating positions and six complete directory information units in name order, three English and three Chinese, each unit consisting of two drums one above the other. Every operator has access to a complete English and Chinese unit. Two views of this C.I.B. are shown in Fig. 2.



NEIL JAMES & CO LTD (SCOTCH BAKERY)		
	1489 YUYUEN	23099
BRANCHES :		
157 NANKING		12765
325 Av JOFFRE		74859
135 SAYZOONG		76252
NESTLE'S MILK PRODUCTS (CHINA) LTD		
	9 QUAI FRANCE	82080
(2 lines) Private Exchange to all Depts		
NESWADBA A MRS	Ps 159 25 Av HAIG	70855
NETESSOFF A	Ln 150 4 BAIKAL	50403
NETHERLANDS CONSULATE GEN	9 QUAI FRANCE	80136
NETHERLANDS SELLING ORGANISATION LTD		
	45 KIUKIANG	19970
GODOWN	Ln 300 61 ICHANG	38609
NETHERLANDS TRADING SOCIETY	20 BUND	19474
AFTER OFFICE HOURS :		
MANAGER		19471
SUB MANAGER		19472
CASHIER		19473
RESIDENCES :		
SCHAAP C J MANAGER	1594 Av JOFFRE	74655
VAN WEEZEL ERRENS J P A		
	1202 Av JOFFRE	71104
NETUPSKY A M OFFICE	330 SZECH	18580
RESIDENCE	313 G de BSZON	79657
NEW AMERICAN PHOTOGRAVURE PRESS		
	Ps 223 8 ZIKAWEI	72964
NEW ASIA HOTEL	422 TIENDONG	42210
NL MANAGER'S OFFICE		45226
NL IMOTO K RESIDENCE	Ln 175 21 E KASHING	45252
* NEW YORK TIMES	220 SZECH	19253
IF NO ANSWER CALL	TEL ANS SERVICE	97222
NEW YORK TIMES	NUMBER RESERVED	
NEW ZEALAND INS CO LTD	27 BUND	19593
NEWELL H	525 EMBANKMENT BLDG	45251
NEWS REEL THEATRE	304A MOHAWK	35657
NEWSON C C	43 TUNSIN	23568
NEYRONE L	73 GT WESTN	21061
NG CHEW	722 YUYUEN	21522
NG KA WING	153-C SOEURS	76711
NG W C	Ln 10 26-D SEYMOUR	38028
NG YING KAI	Ps 687 2 Av FOCH	76013
NGAI KUNG KWAN	Ln 189 47 KINNEAR	20742
NGO KING LOONG	Ln 230 VV17 AMOY	91561
NIAGARA AERATED WATER FTY	216 FRELUPT	76796
NICHIBEI MOTOR CAR CO	615-7 N SZECH	41063
NOZAKA BROS & CO LTD	24 CENTRAL	16880
BRANCH	201 KINGHONG	43664
NYI KUNG KWAN	278 WEIHAIWEI	32777
NYI LOH FUNG	NUMBER RESERVED	
O & K PRINT CO	Ps 116 7 Av JOFFRE	86934
O'BOLGER ROBERT E	168 GHISI	73911
O K SHIRT & TIE CO	1281 AVENUE	62498
OAK & CO GENERAL CONTRACTOR		
	209 Y M YUEN	14177
OCEAN ACCIDENT & GUARANTEE CORP LTD		
(CHINA) BRANCH	17 CANTON	13407
(4 lines) Private Exchange to all Depts		

FIGURE 3.

Fig. 3—Frame Showing English Directory Information Listings.

3. Maintenance of Information Records

In Shanghai, the English directory information is typed and filed in alphabetical order of names; Chinese listings are written and filed in 'stroke' sequence which may be regarded as the Chinese equivalent of the alphabet. The method of indexing the English files is to show the letter of the alphabet on an index tab at the beginning of the section referring to that letter; thereafter, the index tab bears the first three letters of the first and last names listed in the frame (Fig. 3). The method of indexing the Chinese files is somewhat different. The Chinese language has a large number of 'characters,' each of which is built up by a number of 'strokes'; characters having from 1 to 27 strokes are most generally used in names. For reference purposes, all characters having the same number of strokes are grouped together, there being a varying number of characters in each group. There are, for example, two characters having one stroke, 55 having 5 strokes and 15 having 21 strokes. The method of indexing is indicated in Fig. 4. The first index tab shows four characters having ten strokes, the centre tab indicates that the eleven stroke series is commencing, while the third tab shows the first character having eleven strokes. To facilitate reference to the files, an insert indicating the stroke series is filed at the top of each frame; also, an insert showing the change to the next stroke series is filed immediately above the first listing of that series. For example, the top insert of the sample frame reads 'Stroke Ten' while the eighth insert from the bottom reads 'Stroke Eleven.'

Information concerning connections, disconnections and changes is obtained from the No. 1 copy of the Service Orders issued by the Business Office. Upon receipt of a connection order which affects directory listings, an insert is prepared for each directory unit and attached to the service order. Immediately the Plant Department notifies C.I.B. Records that the work is completed, the service order is extracted from the pending file and the inserts are filed in the rotary files, the information being available to callers within approximately five minutes after the completion advice is received. In the case of disconnections, the appropriate inserts are extracted from the rotary files immediately the advice of completion is received. Incidentally, in normal times, approximately 80% of the total service orders issued by the Business Office affects directory listings, whereas under the sub-normal conditions which at present prevail in Shanghai, only about 45% involves the C.I.B. files; this represents approximately 60 to 100 changes per day in each directory unit as against 130 to 220 in normal times.

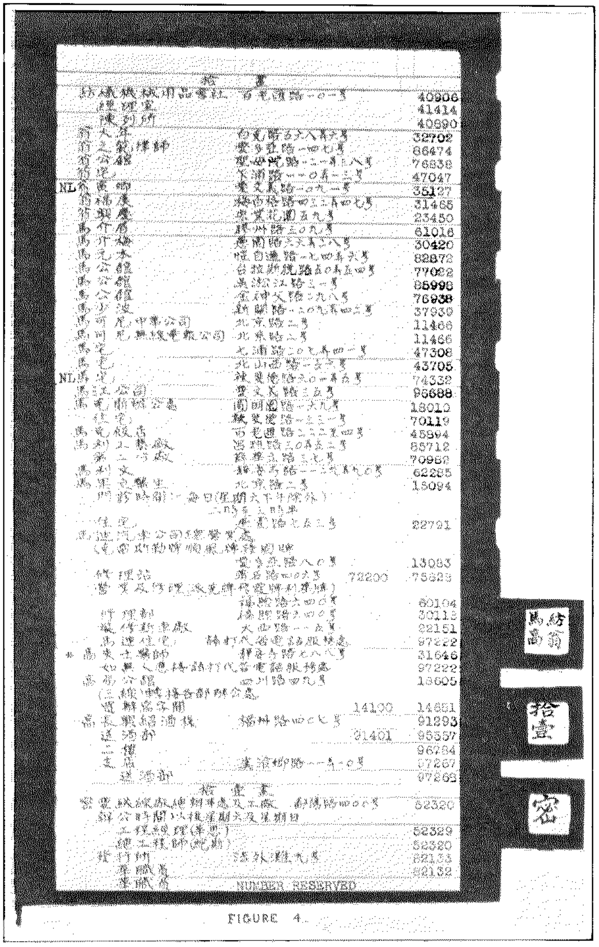


Fig. 4—Frame Showing Chinese Directory Information Listings.

As far as possible every effort is made to use only one strip for each listing, and to this end abbreviations have been developed and standardised, these being used where necessary for specified words and streets; in addition, all words such as 'The,' 'Road,' 'Street' and 'Avenue' are eliminated.

When maintaining the files, consideration also must be given to Directory requirements; for, since 1934, the C.I.B. information records have served the printers for obtaining the information used in the compilation of the alphabetical sections of the English and Chinese directories, the rotary file frames being photographed and the type set from the photographs.

Every subscriber is entitled to one line in the directory free of charge but many subscribers require, and pay for, additional listings. Furthermore, the amount of space allowed free to each subscriber for his directory listing is equal to 51 printing spaces, while the strip used in the C.I.B. files has only 47 typing spaces. Thus, if it is necessary for a subscriber's directory listing to occupy the full 51 spaces allowed, the C.I.B. must utilise two flexoline inserts for the rotary file listing. In order to meet both directory and rotary file requirements, therefore, the use of one strip in the files is not rigidly enforced, even when practicable through the use of abbreviations.

4. *Development of Information Records*

In order to provide for expansion it is necessary to ascertain exactly how many inserts are used for each subscriber's listings and from this knowledge compile what is known as a 'double listing' factor. The Shantelco 'double listing' factors, which have remained constant since October 1938, are 1.09 for the English files and .90 for the Chinese files, the latter figure being lower due to the fact that foreign residential listings are not shown in the Chinese records or directory, owing to the difficulty of accurate translation into Chinese.

Further, due to the constant movement of subscribers, it is impracticable to fill each frame with inserts to its full capacity. In order to avoid unnecessary loss of time when new listings are being filed and to ensure speedy maintenance, it is therefore essential to determine the percentage of each frame which should normally be filled, this factor being known as the 'percentage file fill.' Each of the frames has a capacity of 140 flexoline inserts, 70 on each side, and various 'file fill' factors have been experimented with; it has, however, been found that the most satisfactory figure is around 85%. Using this figure, the total working capacity of each directory unit is 107,000 inserts. Under present sub-normal conditions it would be practicable to work to a 90% fill, thus increasing the total capacity of one directory unit to 113,400 inserts, but, pending a clarification of the situation, no file fill adjustment has been made.

These 'file fill' and 'double listing' factors are used in estimating the period over which a rotary file directory unit will serve, and are applied to the estimated number of exchange lines for the particular period under review.

Thus, from reference to Table I, it will be realised that under normal conditions, where English and Chinese language files are used and every operator has access to both complete sets of records, file development is governed to some extent by the number of listings which can be accommodated in the English file. Assuming a 'file fill' factor of 85% and 'double listing' factors of 1.09 and .90 for English and Chinese files, respectively, the saturation point of one English directory information unit of two drums will therefore be reached when the system attains approximately 98,000 lines, and of three, four and five drum units when it reaches around 147,000, 196,500 and 245,600 lines respectively. The same sized directory units would, however, accommodate Chinese listings for approximately 119,000, 178,500, 238,000 and 297,500 exchange lines before saturation is reached. Furthermore, if directory records in only the English language were maintained it would be possible to use rotary files up to a ten drum unit (approximately 491,000 exchange lines), every operator having access to a complete directory unit.

TABLE I

File Capacity in Relation to Exchange Lines

File fill—85%

Double listing factors— { 1.09 English / 0.90 Chinese }

No. of Drums in a Directory Unit	Insert Capacity	Exchange Line Capacity	
		English File	Chinese File
2	107,100	98,257	119,000
3	160,650	147,385	178,500
4	214,200	196,514	238,000
5	267,750	245,642	297,500

When planning C.I.B. file development, the problem cannot be considered entirely from the file capacity point of view since the question of operating costs is also of vital importance. The

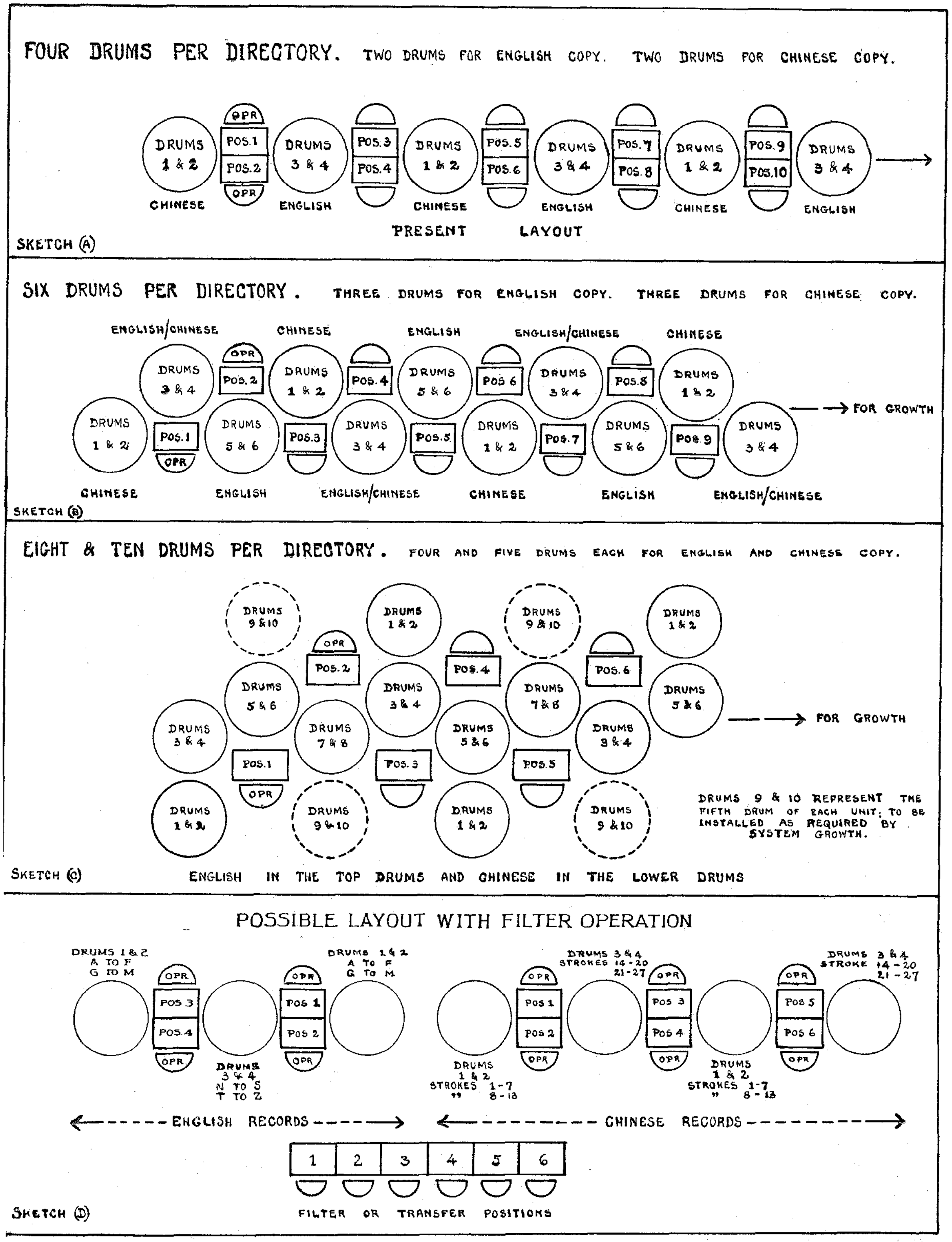

FOUR DRUMS PER DIRECTORY. TWO DRUMS FOR ENGLISH COPY. TWO DRUMS FOR CHINESE COPY.
DRUMS 1 & 2
CHINESE
OPR
POS. 1
POS. 2
DRUMS 3 & 4
ENGLISH
POS. 3
POS. 4
POS. 5
POS. 6
POS. 7
POS. 8
POS. 9
POS. 10
PRESENT LAYOUT
SKETCH (A)
SIX DRUMS PER DIRECTORY. THREE DRUMS FOR ENGLISH COPY. THREE DRUMS FOR CHINESE COPY.
ENGLISH/CHINESE
DRUMS 5 & 6
FOR GROWTH
SKETCH (B)
EIGHT & TEN DRUMS PER DIRECTORY. FOUR AND FIVE DRUMS EACH FOR ENGLISH AND CHINESE COPY.
DRUMS 9 & 10
DRUMS 7 & 8
DRUMS 9 & 10 REPRESENT THE FIFTH DRUM OF EACH UNIT; TO BE INSTALLED AS REQUIRED BY SYSTEM GROWTH.
SKETCH (C)
ENGLISH IN THE TOP DRUMS AND CHINESE IN THE LOWER DRUMS
POSSIBLE LAYOUT WITH FILTER OPERATION
DRUMS 1 & 2 A TO F G TO M
DRUMS 3 & 4 N TO S T TO Z
DRUMS 3 & 4 STROKES 14-20 21-27
DRUMS 1 & 2 STROKES 1-7 " 8-13
ENGLISH RECORDS
CHINESE RECORDS
1
2
3
4
5
6
FILTER OR TRANSFER POSITIONS
SKETCH (D)

Fig. 5—Present and Possible Directory Information Bureau Layout Designs.

number of directory information units increases in proportion to the required number of operating positions, which in turn are governed primarily by the number of calls made to the information bureau per line per busy hour. These also are studied in relation to the operating time per call, that is, the time taken by the information operator to ascertain the caller's requirements and supply the required information.

The calling rate tends to increase in relation to the time elapsed since the issuance of the directory, due to the increase in directory listing obsolescence. Records show that the amount of obsolescence varies from about 6% immediately after issuance to about 34% when the C.I.B. files are photographed for the next issue of the directory. The calling rate per line per busy hour for February, 1941, just prior to the issuance of the directory, was .00912, whilst the figure immediately after issuance was .00768. The present operating time for calls to C.I.B. is around 52 seconds; Chinese calls, which represent approximately 90% of the file references, take a little longer to handle than English calls. This is largely due to difficulty in obtaining the necessary details from Chinese subscribers, the operator often having to ascertain first the number of 'strokes' in the surname, some names being found under more than one 'stroke'; for example, the name 'Wong' can be found under 'strokes' 4 and 12. The operator frequently must also ascertain the number of 'strokes' in the given name or names and the manner of writing the characters before accurate information can be given to the caller. To a certain extent, however, information calls are answered by the operators from memory, that is, without reference to the files; roughly 22.5% of the Chinese, and 14% of the English calls, are so handled.

Under existing world conditions it is extremely difficult to make forecasts but, so far as can be estimated from information at present available, it will probably be about 1946 before the system reaches 98,000 lines, at which time the existing two drum directory information units will probably reach the saturation point. Nevertheless, a study of the problem of C.I.B. information file development was made during 1940, when three policies were given consideration: first, an extension of the present full rotary system; second, rotaries for Chinese records and directories with daily addenda sheets for English records; and third, directories with daily addenda sheets for both English and Chinese records. In the latter two policies the daily addenda sheets would be supplied by the printer who would also have to issue periodic, probably bi-weekly or weekly, reprints of the directories for the use of the Information operators. The studies were made in collaboration with the Commercial Department Directory Section and disclosed that it would be desirable to continue with the full rotary system as long as possible, particularly since it provides such a satisfactory basis for the printing of the alphabetical sections of both directories.

Reference to Table I, indicating the relation of file capacity to exchange lines, and to Fig. 5 shows that, provided the 'double listing' factors and 'file fill' figures previously referred to remain constant, it would be possible, with a re-arrangement of the operating positions, to use rotary files until the system reaches around 245,000 lines. From an operating cost aspect, however, it is doubtful whether the four and five drum directory units will ever be adopted in Shanghai. Assuming that they were adopted, any subsequent development would have to be taken care of by the introduction of the 'filtering' method of operating, under which the call is answered by one operator and distributed or filtered to a disengaged operator who has access to the appropriate section of the records. In this connection it should be mentioned that, while filtering economises in the number of information records required, the total time taken to supply information to subscribers is considerably increased due to the call being handled by two operators. Filtering is therefore usually deferred by most telephone concerns as long as possible, but at some period of system growth its introduction becomes economically desirable. When that time arrives in Shanghai, a scheme approximating the layout shown in (*d*) of Fig. 5 would probably prove workable, the number of positions and the breakdown of the information records depending entirely upon traffic conditions and forecasts at the time of its introduction.

5. Problems Peculiar to Shanghai

Most of the operating difficulties experienced in Shanghai involve language problems. No only is the variety of languages very great, including English spoken with innumerably different accents, but there are also many dialects of the spoken Chinese language, though the written language is the same. While the 'Shanghai' dialect predominates, the large numbers of natives from all over China residing in the city use many other dialects. All the Information operators are able to read and speak English and Chinese (Shanghai dialect) fluently and many are also able to speak Mandarin and Cantonese as well as other dialects.

To facilitate intercommunication between the Shanghai Telephone Company and the Central China Telecommunications Company, all Shantelco operators subsequent to the Sino-Japanese hostilities of 1937 were taught the numerals and operating expressions in Japanese. The operating and supervisory forces also include individuals who can speak Japanese, Russian, Portuguese, Polish, Filipino, French and German.

Most telephone concerns undoubtedly are confronted to some extent with the problem of unnecessary calls made to the information bureau involving numbers correctly listed in the current issue of the directory. In Shanghai separate English and Chinese directories are printed, Chinese directories being issued to Chinese subscribers and English directories to subscribers of other nationalities; subscribers who desire copies of both directories can obtain them by payment of the specified charge. Records taken reveal that approximately 75% of the calls made to the C.I.B. are for numbers listed in the directories; this figure is probably higher than elsewhere and is very largely due to language difficulties as will be seen from the following breakdown:

a)	Foreigner (non-Chinese) using a telephone belonging to a Chinese subscriber with only a Chinese directory available.	21%
b)	Chinese using a telephone belonging to a foreigner with only an English directory available	28%
c)	Inability to read either directory	5%
d)	Chinese calling for a non-Chinese residence (not shown in the Chinese directory)	6%
e)	Unable to find the name required—probably listed under some other name.	4%
f)	Miscellaneous (Directory not at hand; cannot be bothered to look in Directory; quicker to call '09,' etc.)	11%

There does not appear to be any really satisfactory method of eliminating the enquiries mentioned under (*a*) to (*d*), and, so far as the other two items are concerned, various operating procedures intended to induce subscribers to use the directories have been tried out, but reduction in the number of enquiries was found to be small and more than offset by the increased time taken to deal with each call. In accordance with general practice, Shantelco makes no special charge for calls to the directory information bureau. While not directly revenue producing, directory information service, in addition to its intangible value from a 'Good Public Relations' aspect, does undoubtedly improve revenue by stimulating telephone usage, particularly in measured rate areas such as Shanghai.

The Effect of Space Charge on the Potential and Electron Paths of Electron Beams

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In this article the more important results of analyses of the effects of space charge in electron streams are collected from the existing literature and are presented in the form of curves and nomograms so that they can readily be applied to cases occurring in practice. The effects considered are: the space charge limited current in plane and cylindrical diodes; the minimum potential; maximum current and increase of transit time in the screen-anode region of tetrodes; the minimum potential, maximum current, velocity distribution and divergence of a long flat beam between parallel plates and of a long cylindrical beam in a tube.

1. Introduction

When an electron stream passes through an electrode system, the potential at any point is lower than that due to the electrodes themselves in the absence of current, owing to the surrounding negative space charge. In practice, this depression of potential has three important effects:

(*a*) The potential may drop to zero (the value at the cathode) at some point, forming a virtual cathode. Some electrons are brought to rest there, and return to the nearest positive electrode.

(*b*) A beam which would be homogeneous in velocity is rendered inhomogeneous, because the potential is depressed by different amounts in different parts of the beam.

(*c*) Electric fields may be introduced, altering the electron paths; for example, a beam which would otherwise be parallel is caused to diverge by its own space charge.

It is important for design purposes to be able to calculate the magnitude of these effects due to a given current in a given electrode system, but this is possible only in a few cases of simple geometry. Three cases have been treated at length in recent literature:

(*a*) The screen-anode space of an infinite plane tetrode.[1]

(*b*) A flat beam travelling between two parallel lateral plates.[2]

(*c*) A cylindrical beam travelling down a cylindrical tube.[3]

The examples given hereinafter indicate the usefulness of such calculations. In the case of a beam power tetrode, the depression of potential is utilised to suppress the passage of secondaries between screen and anode; in tubes utilising long focused beams, the space charge effects are detrimental because divergence of the beam usually causes loss of current to various electrodes, while velocity inhomogeneity may cause loss of efficiency.

In collecting the main results of the papers referred to above, the aim has been to present them in such a way that they can be applied to practical cases easily and quickly. The possibility of bringing all these results within the scope of a single paper is simplified by the universal appearance in the analyses of a certain parameter, defined in the next section.

For the sake of completeness, the case of the space-charge limited diode (plane and cylindrical) has been included, this being the simplest system whose action is governed by space-charge.

2. The Fundamental Parameter P

It appears that all space-charge effects depend on a current density i, assumed constant in space, a length a and a potential V in such a way that they can be expressed most conveniently in terms of a dimensionless parameter P, first introduced by Salzberg and Heaff,[1] and defined by:

$$P = 3\pi^{1/2}\left(\frac{m}{2e}\right)^{1/4}\cdot\frac{i^{1/2}a}{V^{3/4}}, \tag{1}$$

where e/m is the ratio of charge to mass of an

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[1] For references, see end of article.

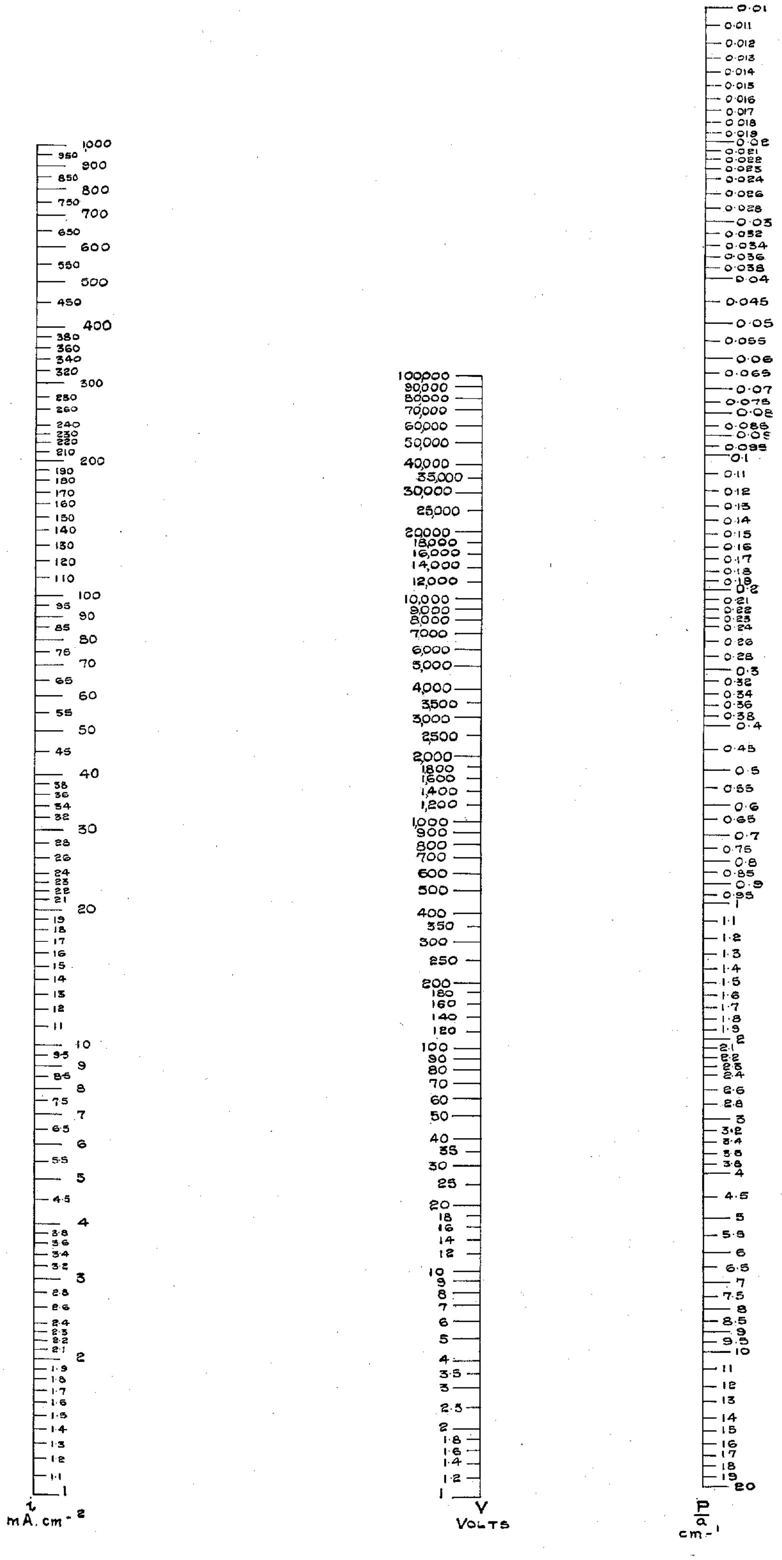
i
mA.cm⁻²
V
Volts
P/a
cm⁻¹

Fig. 1—Nomogram connecting i, V, and P/a according to equation (2).

electron. If i is expressed in mA/cm^{-2}, a in cm, and V in volts:

$$P=\frac{20.8 i^{1/2} a}{V^{3/4}}. \qquad (2)$$

This relation is shown in Fig. 1 by a nomogram connecting P/a, i and V, from which any one of the three quantities can be read off if the other two are given.

We now pass on to the consideration of specific cases, showing how the various space charge effects are related to P. It is to be remembered, however, that, although P is always of the form given in equation (1), the meaning to be ascribed to i, V and a differs from case to case.

3. The Space-Charge Limited Plane Diode

Langmuir's equation for the space-charge limited current through a plane diode is

$$i_a=\frac{1}{9\pi}\left(\frac{2e}{m}\right)^{1/2}\frac{V_a^{3/2}}{l^2}, \qquad (3)$$

where i_a is the current density, V_a the anode potential and l the cathode-anode distance.

Taking the square root and rearranging:

$$3\pi^{1/2}\left(\frac{m}{2e}\right)^{1/4}\frac{i_a^{1/2} l}{V_a^{3/4}}=1. \qquad (4)$$

This is identical with equation (1) if

$$\left.\begin{aligned} i &= i_a \\ a &= l \\ V &= V_a \\ P &= 1 \end{aligned}\right\}. \qquad (5)$$

Hence, if any two of the quantities i_a, V_a, $1/l$ are known, the nomogram at once gives the third, in accordance with equation (3).

4. The Space-Charge Limited Cylindrical Diode

Langmuir's equation in this case is

$$I=\frac{2}{9}\left(\frac{2e}{m}\right)^{1/2}\frac{V_a^{3/2}}{r_a\beta^2}, \qquad (6)$$

where I is the current per unit axial length, V_a is the anode potential, r_a the anode radius, and β the well-known function of r_a/r_c tabulated by Langmuir, r_c being the cathode radius. If i_c is the current density at the cathode surface,

$$i_c=\frac{I}{2\pi r_c}=\frac{1}{9\pi}\left(\frac{2e}{m}\right)^{1/2}\frac{V_a^{3/2}}{r_a r_c \beta^2}. \qquad (7)$$

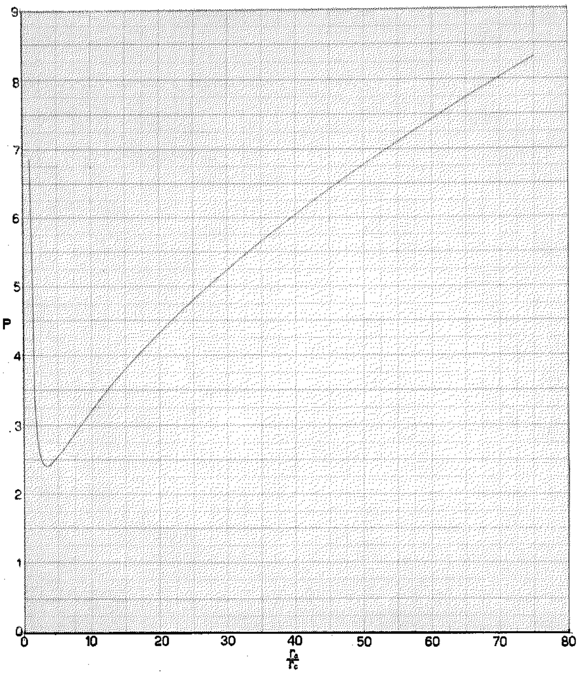

Fig. 2—Cylindrical Diode. Relation between the parameter P and the ratio of the anode radius to the cathode radius r_a/r_c.

This is clearly identical with equation (1) if

$$\left.\begin{aligned} i &= i_c \\ V &= V_a \\ a &= r_a \\ P &= \frac{1}{\beta}\left(\frac{r_a}{r_c}\right)^{1/2} \end{aligned}\right\}. \qquad (8)$$

P is thus a function of r_a/r_c only, and is represented in Fig. 2. Hence, if any one of the four quantities i_c, V_a, r_a, r_c is unknown, it may be determined by the nomogram in conjunction with Fig. 2.

5. Screen-Anode Region of an Infinite Plane Tetrode

Assuming the screen to be infinitely fine, the potential distribution between screen and anode is linear in the absence of space charge. If current passes through the screen to the anode, the space charge has two important effects: first, it lowers the potential in the space, and may form a potential minimum, or a virtual cathode; secondly, it increases the transit time from screen to anode, because the velocity at all points is lower. These effects have been calculated by Salzberg and Haeff [1] and will now be considered in turn.

(*a*) *The Minimum Potential and Maximum Current*

The equation given by Salzberg and Haeff for the minimum value of the potential between screen and anode is

$$P=\left[1-\left(\frac{V_m}{V_g}\right)^{1/2}\right]^{1/2}\cdot\left[1+2\left(\frac{V_m}{V_g}\right)^{1/2}\right] +\left[\left(\frac{V_a}{V_g}\right)^{1/2}-\left(\frac{V_m}{V_g}\right)^{1/2}\right]^{1/2} \cdot\left[\left(\frac{V_a}{V_g}\right)^{1/2}+2\left(\frac{V_m}{V_g}\right)^{1/2}\right]. \quad (9)$$

where V_a, V_g, and V_m are the potentials at the anode, screen and potential minimum, respectively, and P is defined by equation (1) provided

$$\left.\begin{aligned} V&=V_g\\ i&=\text{Density of current from screen to anode}\\ a&=\text{Screen-anode distance}\end{aligned}\right\}. \quad (10)$$

In Fig. 3, V_m/V_g has been plotted against P for several values of V_a/V_g. Thus, if i, V_a and V_g are known, P may be read off from the nomogram, and hence the potential minimum obtained from Fig. 3.

It will be noticed in Fig. 3 that, as P increases (due to increasing i, for example), V_m decreases more and more rapidly till each curve becomes

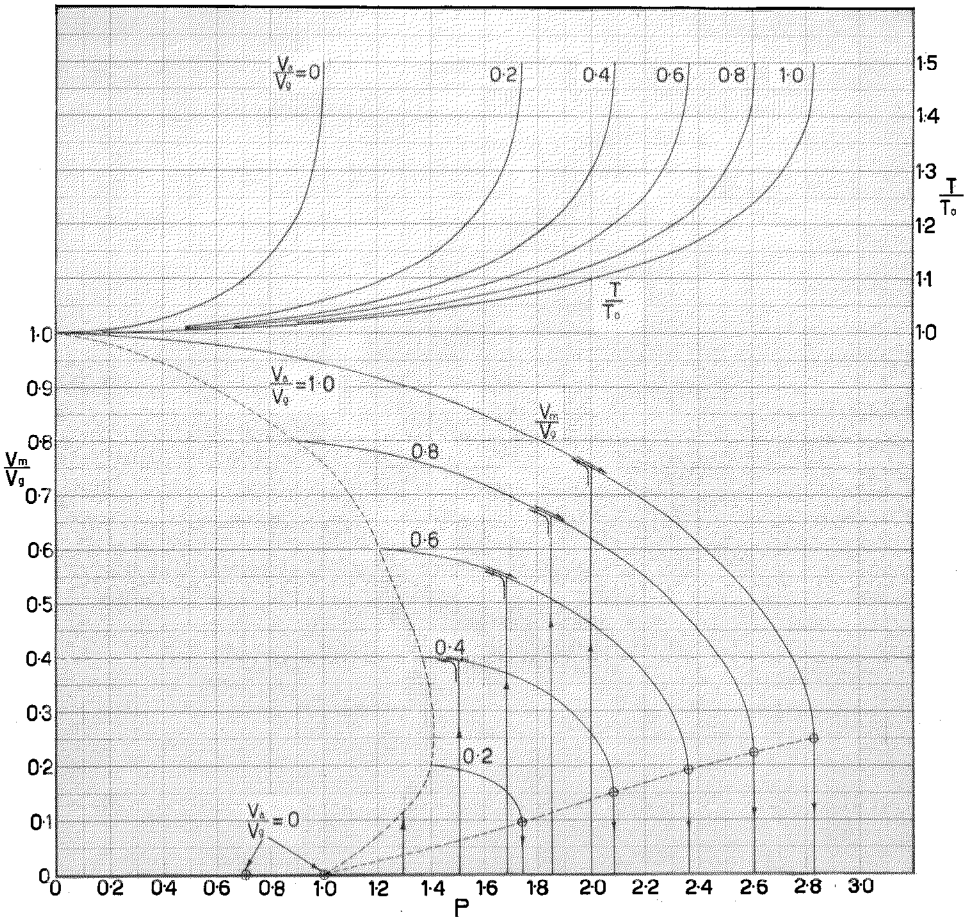

Fig. 3—Screen-Anode space of a tetrode. The upper curves show the variation of transit time T/T_0 with P, the lower curves the variation of minimum potential V_m/V_g with P for several values of V_a/V_g in each case. The downward vertical arrows indicate formation of a virtual cathode, the upward arrows its disappearance.

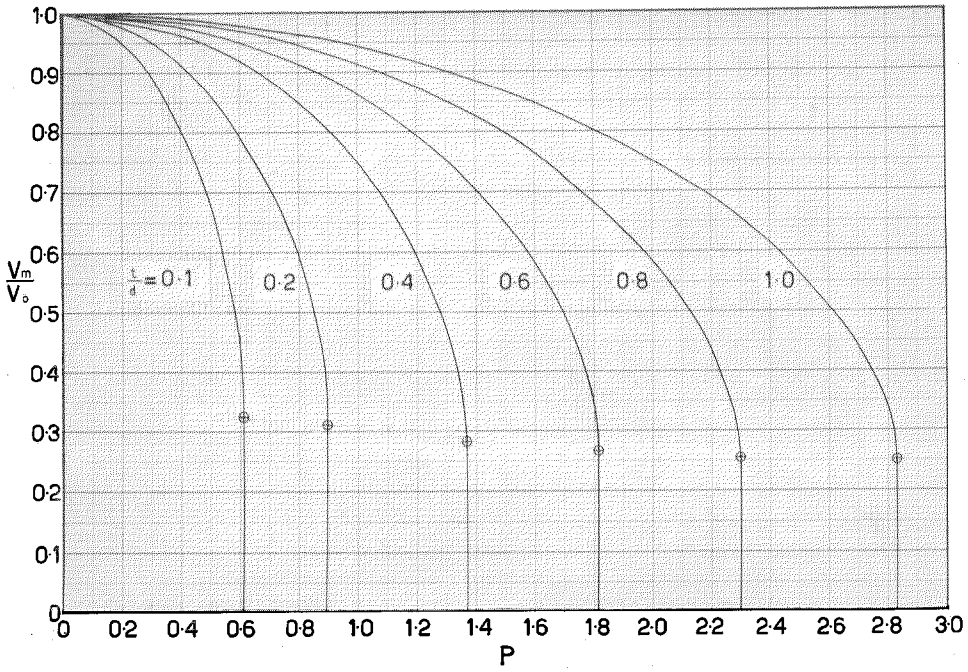

Fig. 4—Flat beam between plates. Variation of minimum potential V_m/V_0 with P for several values of the ratio of beam thickness to distance between plates t/d. A virtual cathode forms at the circled points.

vertical, conditions become unstable, and the potential minimum drops suddenly to zero, forming a virtual cathode. If P is then reduced, the virtual cathode persists for a time until another unstable point is reached when the potential minimum suddenly jumps up to the curve again. The vertical lines represent these sudden jumps in V_m/V_g, the arrows indicating whether upward or downward. For example, referring to the curve for $V_a/V_g=1.0$, V_m/V_g drops from 0.25 to zero at $P=2\sqrt{2}$ ($=2.828$) and jumps from zero to 0.75 at $P=2.0$. The curves for V_a/V_g less than 1.0 are of the same type. The curve for $V_a/V_g=0$ degenerates into a short length of the P axis; when P is increased to 1.0, a potential minimum appears, and is also a virtual cathode. This persists until P is reduced to $\frac{1}{2}\sqrt{2}$ ($=0.707$). In the empty region on the left of the diagram, the potential is not sufficiently depressed to form a minimum. The value of P at which a virtual cathode forms can be used in Fig. 1 to read off the maximum current density that can be passed to the anode.

(b) *The Transit Time*

From equations (8a) and (11) of Salzberg and Haeff, the following equation can be deduced, relating to transit time T to the parameter P and V_g/V_a:

$$P^2=\frac{27\left(\frac{T}{T_0}-1\right)\left[1+\left(\frac{V_a}{V_g}\right)^{1/2}\right]^3}{4\left(\frac{T}{T_0}\right)^3}. \qquad (11)$$

T_0 is the transit time from screen to anode in the absence of space charge; that is,

$$T_0=\frac{a}{v},$$

where $$v=\left(\frac{e}{2m}\right)^{1/2}\left(V_g^{1/2}+V_a^{1/2}\right)$$
= average velocity in absence of space charge.

In Fig. 3, T/T_0 is plotted against P for several values of V_a/V_g, P being read off from the nomogram, with the definitions (10). It will be noticed that T/T_0 reaches the value 1.5 when a virtual cathode sets in, whatever the value of V_a/V_g.

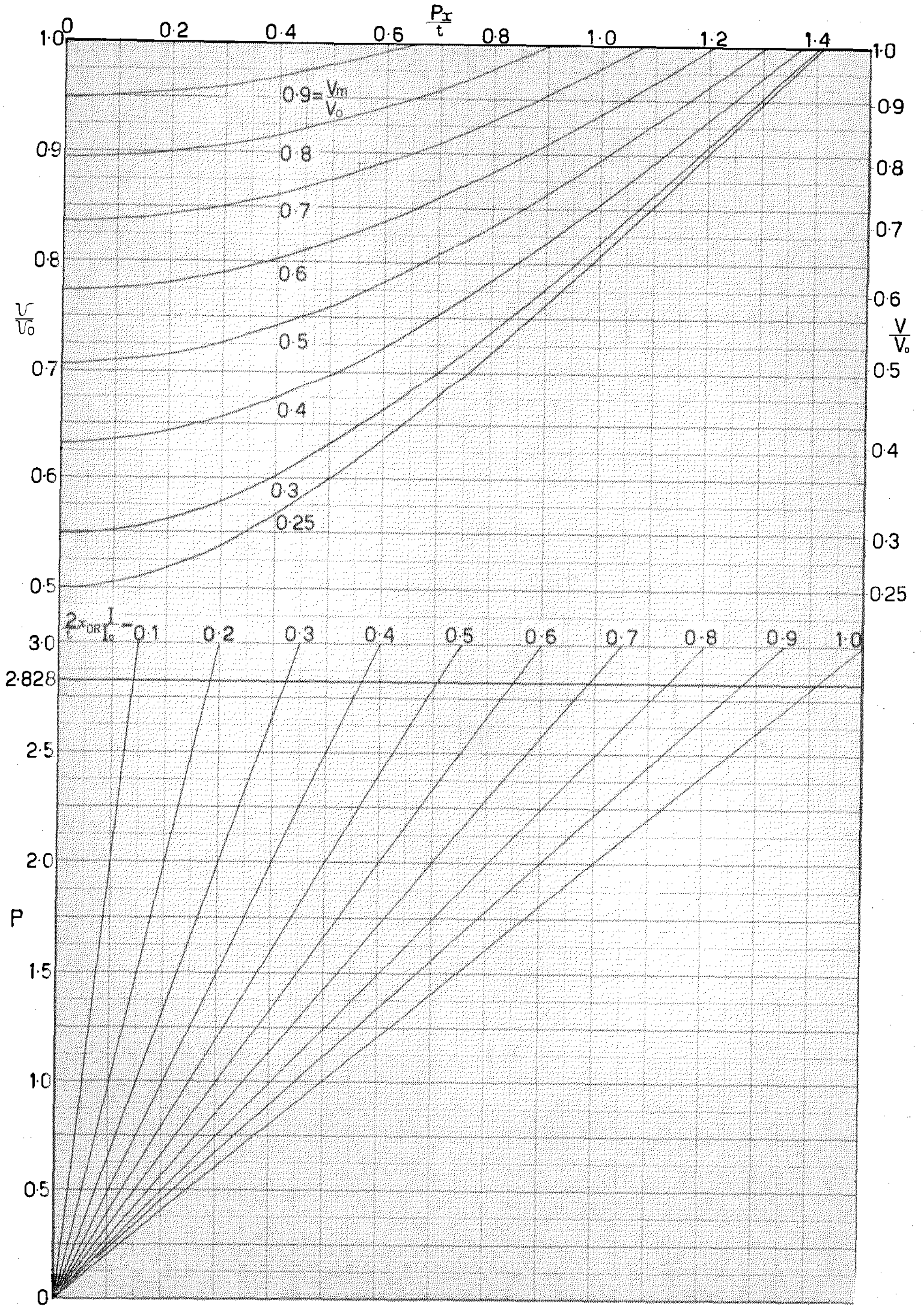

Fig. 5—Flat beam between plates. Distribution of velocity across beam for various values of V_m/V_0 and P. For explanation see section 6(b).

6. Long Flat Beam Between Two Lateral Plane Electrodes

A beam of width t, infinite in length and depth, travels centrally between and parallel to two infinite plates, separated by a distance d. The effects of the space charge are:

(*a*) The potential in the space between the plates is lower than the potential applied to the plates, and is a minimum on the central plane of symmetry of the beam. For a certain current density, a virtual cathode may form, and there is thus an upper limit to the current which can be passed.

(*b*) The beam is inhomogeneous in velocity, the outer parts travelling more rapidly than the centre.

(*c*) There is a lateral field between the beam and plates, which causes the beam to diverge.

The first two effects have been calculated by Haeff,[2] while the third may easily be deduced from his equations.

(*a*) *Minimum Potential and Maximum Current*

From Haeff's equations, V_m/V_0 has been calculated in terms of his function F, V_m being the minimum potential, and V_0 the potential on the plates. Haeff's function F is connected with P by the simple relation

$$P^2=\frac{4Ft}{d}, \tag{12}$$

provided in equation (1)

$$\left.\begin{array}{l} i=i_0, \text{ the current density in the beam} \\ V=V_0, \text{ the applied potential} \\ a=t, \text{ the beam thickness} \end{array}\right\}. \tag{13}$$

In Fig. 4, V_m/V_0 is plotted against P for several values of the ratio t/d. As P increases V_m/V_0 decreases until each curve becomes vertical, conditions become unstable, and V_m drops suddenly to zero forming a virtual cathode. The value of P at which this happens can be used, with the known V_0 and t, to read off from the nomogram the maximum current density that can be passed.

(*b*) *Inhomogeneity of the Beam*

This is represented by plotting the electron velocity against x, the transverse distance from the centre of the beam. The velocity depends also on P and t/d, but these quantities enter into the equations in such a way that, by choosing V_m/V_0 as a parameter, the number of parameters is reduced, and the graphical representation is simplified. The velocity is then of the form

$$\frac{v}{v_0}=f\left(\frac{Px}{t},\frac{V_m}{V_0}\right),$$

where v is the velocity at a distance x from the axis, and v_0 is the velocity corresponding to the applied potential V_0. The function f cannot be written down explicitly, but has been calculated numerically from Haeff's equations for the potential distribution.

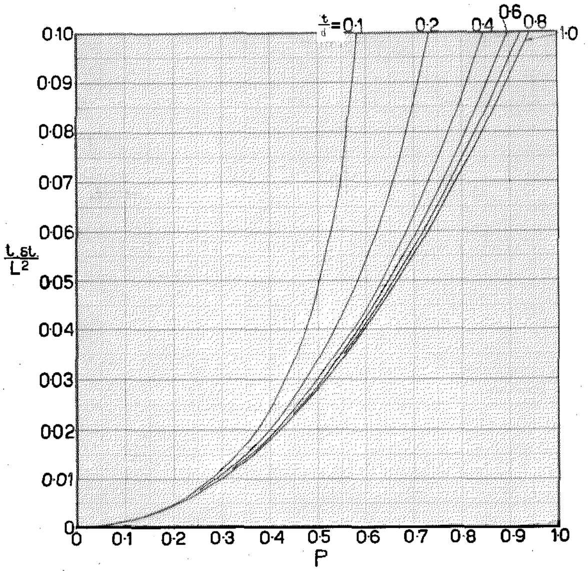

Fig. 6—Flat beam between plates. Variation of divergence function $t\cdot\delta t/L^2$ with P for several values of t/d according to equation (17).

In Fig. 5, v/v_0 is plotted against Px/t for several values of V_m/V_0. A scale of $V/V_0=v^2/v_0^2$ is also given on the right hand side in case the potential distribution across the beam is required.

The set of lines in the lower part of the diagram is intended to derive a scale of $2x/t$ from the scale of Px/t. If a straight-edge is placed horizontally at the appropriate value of P on the left vertical scale, the ten lines will mark off on it a linear scale of $2x/t$ from 0 to 1. Using this as the abscissa scale, the curves in the upper part of the diagram become velocity distribution curves: v/v_0 against $2x/t$. Since $2x/t$ is also the fraction of the total beam current which lies between x and $-x$, one can read off directly the fraction of the total current having velocities between two specified limits, v_1/v_0 and v_2/v_0; it is the interval on the appropriate $2x/t$ scale between the values $2x_1/t$ and $2x_2/t$ corresponding to v_1/v_0 and v_2/v_0.

(c) *Divergence of the Beam*

Since the potential V_a at the edge of the beam is less than the applied potential V_0, the electrons at the edge of the beam are in a transverse field of value

$$E=\frac{2(V_0-V_a)}{d-t}, \tag{14}$$

which accelerates them towards the side plates. The increase in width of the beam δt is easily calculated if $\delta t/t$ is small enough not to alter the current density and transverse field appreciably over the length of the beam considered.

The transverse acceleration of an electron at the edge of the beam is eE/m and hence, if the beam is initially parallel, the transverse displacement is given by

$$\frac{1}{2}\delta t=\frac{eE}{2m}\cdot T^2, \tag{15}$$

T being the time taken by an electron to travel a length L of the beam. Since the axial velocity is assumed constant and corresponds to the potential V_a, L is given by

$$L=\left(\frac{2eV_a}{m}\right)^{1/2}T. \tag{16}$$

Elimination of T between (15) and (16) leads to the equation

$$\frac{t\cdot\delta t}{L^2}=\frac{\dfrac{V_0}{V_a}-1}{\dfrac{d}{t}-1}. \tag{17}$$

V_a/V_0 can be calculated numerically from Haeff's equations for given values of P and t/d. In Fig. 6, $t\cdot\delta t/L^2$ is plotted against P for several values of t/d and thus the divergence δt can easily be calculated when P has been obtained from the nomogram of Fig. 1.

7. *Cylindrical Beam in a Tube*

This case is the axially symmetrical analogue of the preceding one. A cylindrical beam of radius ρ passes down a coaxial cylindrical tube of radius R, the length of the beam and tube being large compared with their radii. The principal space charge effects are:

(*a*) On the axis of the beam the potential is a minimum; and, if the current is great enough, may drop to zero, forming a virtual cathode.

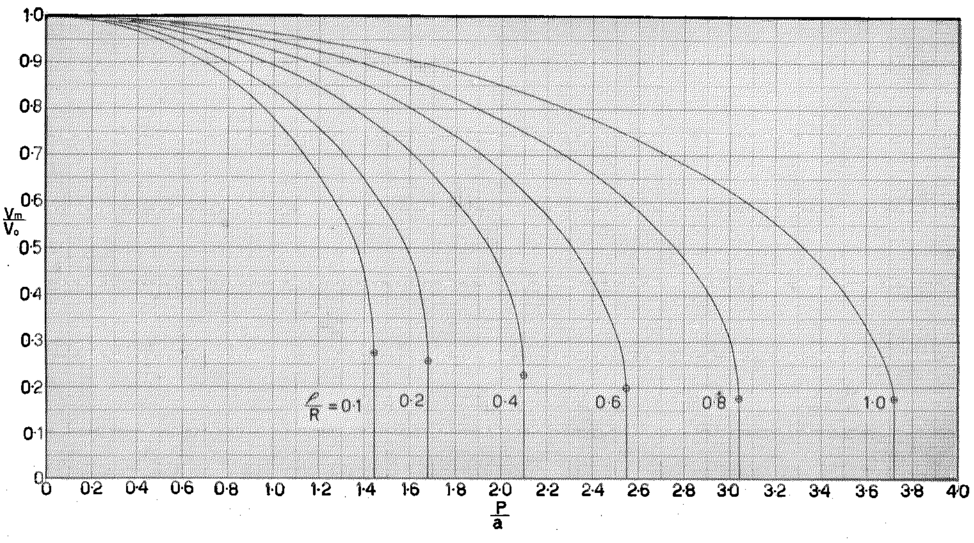

Fig. 7—Cylindrical beam in tube. Variation of minimum potential V_m/V_0 with P/a for several values of the ratio of beam radius to tube radius ρ/R. A virtual cathode forms at the circled points.

The current then stops passing down the tube, and instead drifts radially to the tube.

(*b*) The beam is inhomogeneous in velocity, the outer parts travelling more rapidly than the centre.

(*c*) There is a radial field acting on the outer electrons, causing the beam to diverge.

These effects have been calculated by Smith and Hartman.[3]

(*a*) *Minimum Potential and Maximum Current*

If V_m is the minimum potential, and V_0 the potential on the tube, V_m/V_0 has been calculated from the equations of Smith and Hartman in terms of their function w, which is connected with P by the relation

$$\left(\frac{P}{a}\right)^2=\frac{9\pi w}{4}, \tag{18}$$

provided in equation (1)

$$\left.\begin{array}{l} i=I, \text{ the total beam current} \\ V=V_0, \text{ the applied potential} \end{array}\right\}. \tag{19}$$

It will be noted that in this case a has no independent significance, P/a occurring as a single parameter, and that, in finding it from the nomogram, the total beam current is used, not the current density.

In Fig. 7, V_m/V_0 is plotted against P/a for several values of ρ/R. The curves are qualitatively similar to those of Fig. 4 for flat beams, and each indicates the formation of a virtual cathode at a certain maximum value of P/a. Using this value of P/a, the maximum current which can be passed at any given potential can be read off from the nomogram.

(*b*) *Inhomogeneity of the Beam*

This is best represented by plotting the electron velocity against $(r/\rho)^2$ where r is a radial coordinate measured from the central axis. The velocity depends also on P/a and ρ/R, but, as in the case of flat beams, the number of parameters is reduced by choosing V_m/V_0 as a parameter. The velocity is then found to be of the form

$$\frac{v}{v_0}=f\left(\frac{P}{a}\cdot\frac{r}{\rho},\frac{V_m}{V_0}\right),$$

where v is the velocity at a radius r, and v_0 the velocity corresponding to the applied potential V_0. The function f has been calculated numerically from the equations of Smith and Hartman, and the result is shown in Fig. 8, where v/v_0 is plotted against $(P/a\cdot r/\rho)^2$ for several values of V_m/V_0. A scale of $V/V_0=v^2/v_0^2$ is also given on the right hand side.

The set of parabolae in the lower part of the diagram serves to derive a scale of $(r/\rho)^2$ from the scale of $(P/a\cdot r/\rho)^2$. If a straight-edge is placed horizontally at the appropriate value of P on the left vertical scale, the ten curves mark off on it a linear scale of $(r/\rho)^2$ from 0 to 1. The quantity $(r/\rho)^2$ is also the fraction of the total current which lies within a radius r, and for this reason $(r/\rho)^2$ was chosen in preference to r/ρ as the abscissa scale for the velocity distribution curves. It is thus possible to read off directly the fraction of the total current having velocities between two specified limits, v_1/v_0 and v_2/v_0; it is the interval on the appropriate $(r/\rho)^2$ scale between the values corresponding to v_1/v_0 and v_2/v_0.

(*c*) *Divergence of the Beam*

Equation (18) of Smith and Hartman gives the divergence provided it is so small that the longitudinal velocity and radial field do not alter appreciably over the length of the beam. If the initial radius of the beam ρ increases to ρ' over a length L of the beam, the equation is of the form

$$\frac{L}{\rho}=F\left(\frac{P}{a},\frac{\rho}{R}\right)\int_0^{(\log \rho'/\rho)^{1/2}} e^{x^2}dx. \tag{20}$$

This is represented in Fig. 9 by means of a nomogram in conjunction with a family of curves. The left scale of the nomogram represents L/ρ, and the right scale the divergence ρ'/ρ. The middle scale represents the function $F(P/a, \rho/R)$ which itself has no particular physical significance and is therefore graduated in arbitrary units, but has been calculated in terms of P/a and ρ/R from the equations of Smith and Hartman.

The family of curves relates F to P/a for several values of ρ/R. Thus the procedure is as follows: Given I and V_0, P/a can be read off from Fig. 1. Choosing the appropriate curve in Fig. 9, this value of P/a gives a point on the F scale. If a straight-edge is placed across the nomogram so as to pass through this point, it will mark off a pair of corresponding values of L/ρ and ρ'/ρ.

8. Conclusion

In designing devices employing long parallel beams, either flat or cylindrical, it is important to know what factor limits the current in the beam and what the maximum current is. In all cases likely to occur in practice, the divergence of the beam (if not prevented) sets a limit to the permissible current. If, however, the divergence can be rendered innocuous, a much larger current

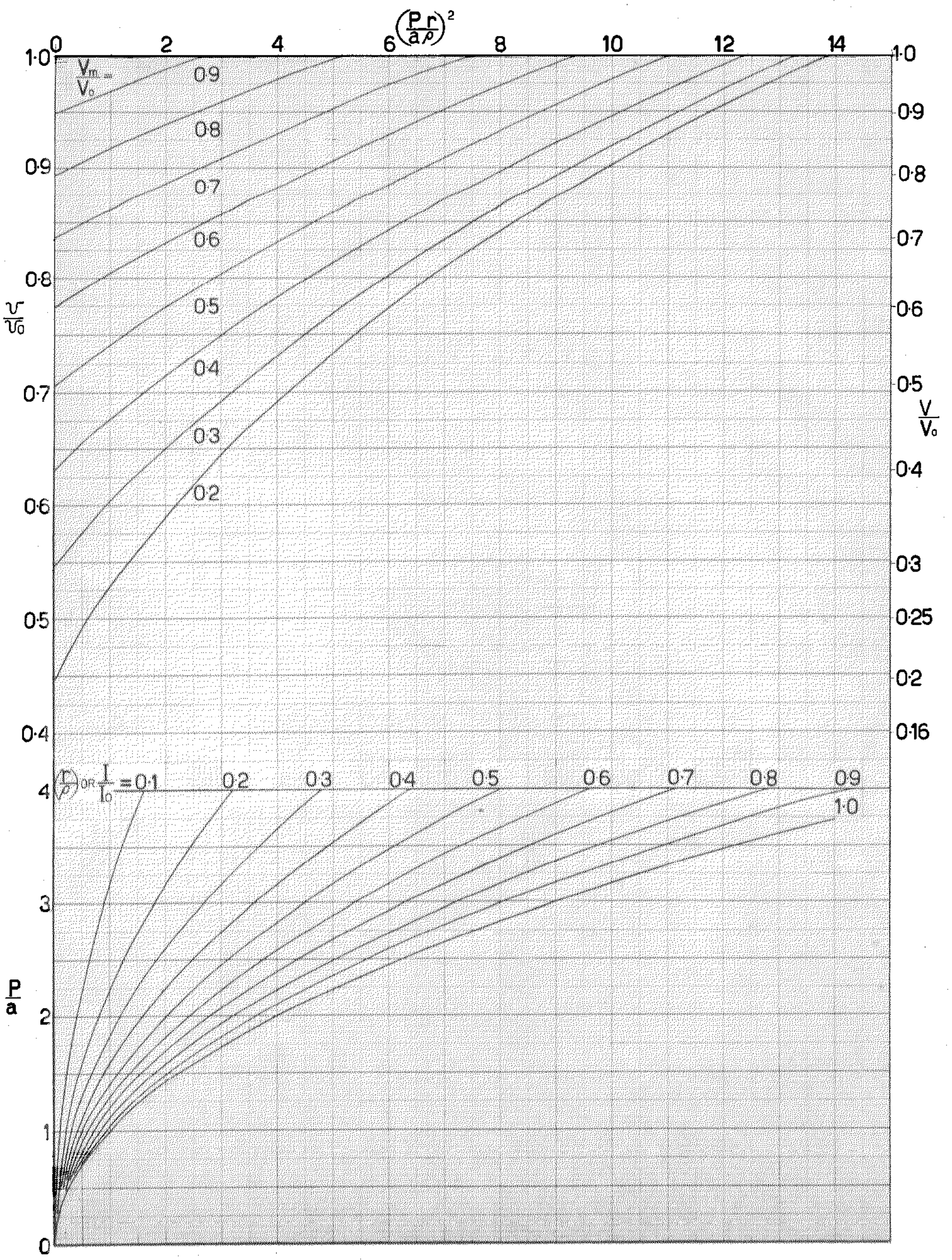

Fig. 8—Cylindrical beam in tube. Distribution of velocity and potential across beam for various values of V_m/V_0 and P/a. For explanation see section 7(b).

can be allowed before another limit is set by the formation of a virtual cathode. For example, a cylindrical beam has a length five times its diameter, and its diameter is 0.8 that of the surrounding tube; if a 10% increase in diameter can be tolerated, Fig. 9 shows that $P/a = 0.25$, which, from Fig. 1, corresponds to a beam current of 4.5 mA at 1,000 volts. If the divergence is prevented, Fig. 7 shows that a virtual cathode will form when $P/a = 3.04$, corresponding to a current of 700 mA at 1,000 volts. The divergence may be prevented by an adequate longitudinal magnetic field. On the other hand, a beam of positive ions travelling in the opposite direction to the electron beam, and coincident with it, by neutralising the space charge, will prevent

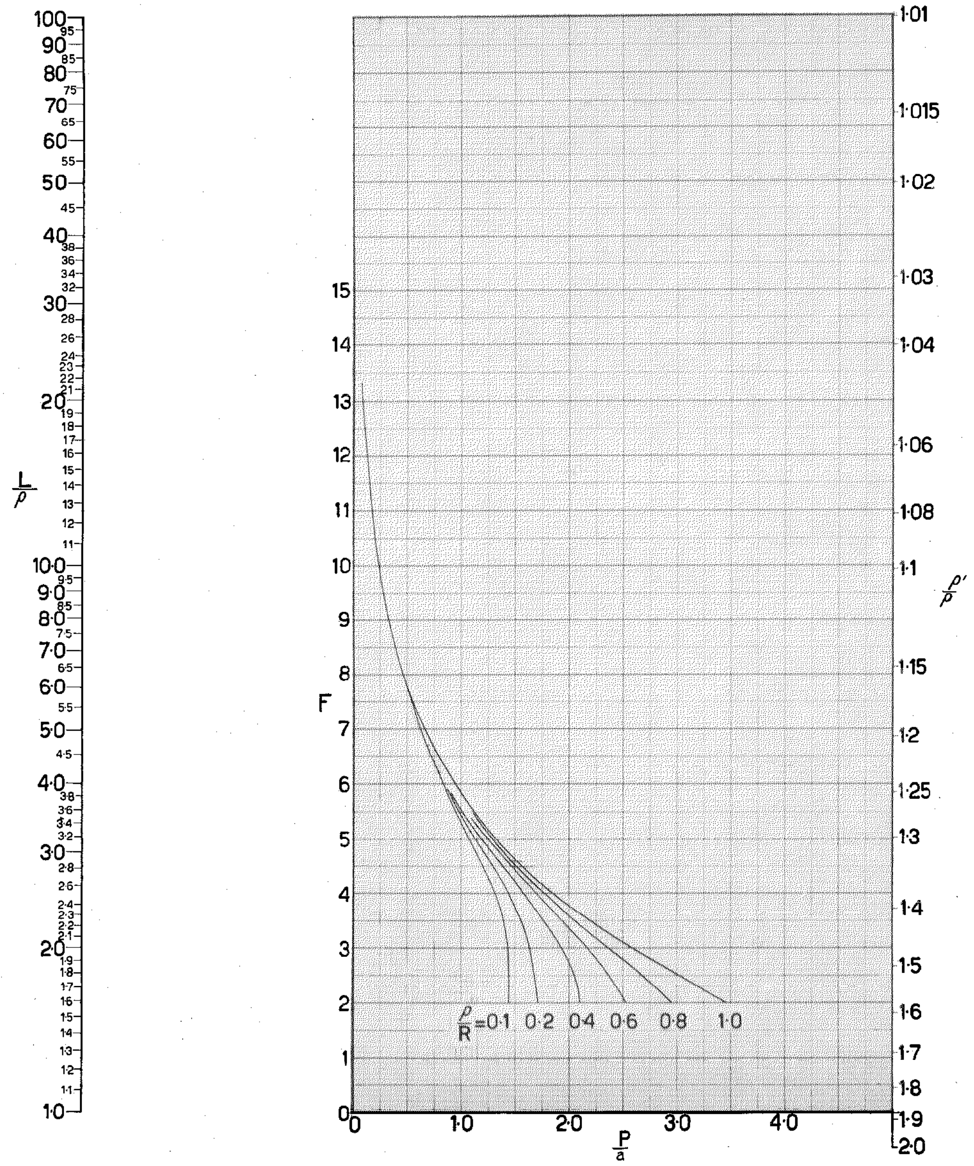

Fig. 9—Cylindrical beam in tube. Nomogram connecting divergence ρ'/ρ, ratio of length to radius of beam L/ρ, and function F (central scale) which is related to P/a by curves for several values of ρ/R.

both divergence and virtual cathode formation.

An interesting distinction between cylinder and flat beams may be made here.

In the case of cylindrical beams, the potential distribution (V/V_0 in terms of r/ρ) depends on the ratio of the beam radius to the tube radius ρ/R, also on the applied potential V_0 and on the total current, but not on the actual radius of the tube. Thus in the above example, a current of 700 mA will form a virtual cathode whatever the radius of the tube is, so long as ρ/R and V_0 are constant. Similarly, a smaller current will produce a minimum potential V_m/V_0 independent of the tube radius. The divergence ρ'/ρ is independent of the tube radius if ρ/R, V_0, L/ρ, and the current are constant; but if L is kept constant instead of L/ρ, the statement is true if the current density is constant, not the current.

In the case of flat beams, the potential distribution (V/V_0 in terms of x/t) depends on the ratio of the beam width to the distance between the plates t/d, on the applied potential V_0 and on the product it^2, i being the current density. In place of it^2 we can write It, where I is the current per unit depth. Thus if t/d and V_0 are fixed, a definite value of It will give rise to a virtual cathode, and hence the closer the plates the greater the current per unit depth that can be passed. If V_0 and t/d are fixed, the divergence $\delta t/t$ depends on the product It (approximately proportional for small divergences) if L/t is constant; but, if L is kept constant, $\delta t/t$ depends on the current density i (again approximately proportional) and is otherwise independent of the thickness t.

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[1] "Effects of Space Charge in the Grid-Anode Region of Vacuum Tubes," by B. Salzberg and A. V. Haeff, *R. C. A. Review*, January, 1938.

[2] "Space-Charge Effects in Electron Beams," by A. V. Haeff, *Proceedings of the I. R. E.*, September, 1939.

[3] "Formation and Maintenance of Electron and Ion Beams," by L. P. Smith and P. L. Hartman, *Journal of Applied Physics*, March, 1940.

Theory of the Magnetron*

By LÉON BRILLOUIN

1. Introduction—General Observations on the Part Played by the Magnetic Field

FOLLOWING Hull's original work on magnetrons, a large number of theories have been formulated; the majority, however, appear inadequate or inexact. Certain authors considered the electronic motion whilst neglecting the space charge; others, the space charge computed by Langmuir for a diode without a magnetic field. Such studies necessarily are highly inaccurate since a powerful magnetic field considerably modifies the electronic paths and, consequently, the space charge. Contrariwise, authors who have endeavoured to evaluate the space charge in the presence of a magnetic field do not appear to have provided practicable solutions. It therefore appears necessary to consider the problem afresh and to compute directly both the space charge and the potential distributions in the magnetron; without these essential data, the development of a coherent theory is impossible.

Larmor's theorem[1] cannot be applied to the magnetron since it is invalid unless the rotation produced by the magnetic field be extremely low and is, therefore, of negligible interest in connection with the present study. Actually the theorem is applicable only where the magnetic field does not appreciably modify the anode current.

A more comprehensive theory, on the other hand, immediately yields an important result. It is known that, in the presence of a magnetic field, the definition of the components of the momentum must be modified (in non-relative mechanics, valid for low speeds) such that:

$$p_x = mv_x + eA_x; \quad p_y = mv_y + eA_y; \quad p_z = \cdots \qquad (1)$$

where m is the electron mass, e its charge (negative) and A_x, A_y, $\cdots$ components of the potential vector. Assuming a constant magnetic field H, directed towards Oz, the potential vector is written:

$$A_x = -\tfrac{1}{2}\mu_0 Hy; \qquad A_y = \tfrac{1}{2}\mu_0 Hx; \qquad A_z = 0; \quad (2)$$

μ_0 being the magnetic permeability in vacuum. If, also, the electric forces present a cylindrical symmetry with respect to Oz, a theorem of conservation of the moment of momentum in the plane xy is applicable:

$$J = p_y x - y p_x = C,$$

which gives

$$J = m(xv_y - yv_x) + \tfrac{1}{2}\mu_0 e H r^2 = C. \qquad (3)$$

This means that the angular velocity $\dot{\theta}$ around the axis Oz is completely defined by the condition

$$J = mr^2\dot{\theta} + \frac{1}{2}\mu_0 e H r^2 = C, \qquad \dot{\theta} = \omega_H - \frac{C'}{r^2}, \qquad \omega_H = -\tfrac{1}{2}\mu_0 \frac{e}{m} H; \qquad (4)$$

where C' is a constant determined by the initial conditions, and ω_H Larmor's velocity of rotation, which reappears here in rigorous form. The result (4) will be found again in the equations of movement. It is well known from Hull's work but it seems useful to establish its relationship with the general theorem (1) on the definition of moments.

To determine the orders of magnitude: if H be measured in gausses whilst all the equations are written in E.S.C.G.S. units, it is necessary to take:

$c = 3 10^{10}$ (velocity of light); on the other hand,

$-\frac{e}{m} = +5.3 \cdot 10^{17}$ E.S.C.G.S.

since e is negative; then

$$\omega_H = 0.884 \cdot 10^7 H, \qquad (5)$$

which, for a field of 500 gausses, gives a rotation speed of 4.42×10^9.

2. Cylindrical Magnetron—Static Case

The magnetron is assumed to consist of a filament of radius a and a cylindrical anode of radius R, the magnetic field H accurately paralleling the filament (axis Oz). It is assumed that electrons without appreciable speed are emitted from the filament, and that the electric field on the filament is zero provided the anode current is below saturation; hypotheses which have both been generally accepted since they were formulated by Langmuir. Distribution of the cylindrical space charge can thus be obtained if the potential V is solely a function of r. The equations of movement follow

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* Paper prepared in January, 1939, while the author was Consultant for Laboratoires Le Matériel Téléphonique, Paris, France. Since then the author has discussed the conditions of oscillation in magnetrons: vide *Physical Review*, Vol. 60, No. 5, pp. 385–396, September, 1941.

[1] For the classical theories, see: L. Brillouin, "l'Atome de Bohr," Presses Universitaires, Paris 1931, p. 107, 124, 134.

$$\left\{\begin{aligned} m\ddot{x} &= -e\frac{\partial V}{\partial x}+\mu_0 e v_y H = -e\frac{\partial V}{\partial r}\frac{x}{r}+\mu_0 e\dot{y}H, \\ m\ddot{y} &= -e\frac{\partial V}{\partial y}-\mu_0 e v_x H = -e\frac{\partial V}{\partial r}\frac{y}{r}-\mu_0 e\dot{x}H. \end{aligned}\right. \tag{6}$$

The static case, which will first be considered, is characterized by the fact that V does not depend on time.

By multiplying the first equation of (6) by $-y$ and the second by x, adding and integrating, the integral of the moment of momentum (3) and (4) are directly obtained.

The constant C' of (4) is determined by the fact that electrons are emitted without speed from the filament, such that $\dot{\theta}$ is zero for $r=a$;

$$\dot{\theta}=\omega_H\left(1-\frac{a^2}{r^2}\right). \tag{7}$$

The Lorentz force, due to the magnetic field H, does not influence the velocity since it is perpendicular to the latter. Energy conservation, accordingly, may be written:

$$\tfrac{1}{2}mv^2+eV(r)=\tfrac{1}{2}m(\dot{r}^2+r^2\dot{\theta}^2)+eV(r)=C,$$

and this new constant is zero if

$$V(a)=0 \text{ on the filament;} \tag{8}$$

hence

$$\dot{r}^2+\omega_H^2r^2\left(1-\frac{a^2}{r^2}\right)^2+\frac{2e}{m}V(r)=0. \tag{9}$$

The equations of movement, therefore, may be integrated directly from (7) and (9) without determining the potential distribution as a function of r.

In (9) one result is at once evident: since the velocity of rotation $\dot{\theta}$ is determined by the magnetic field, the kinetic energy at the distance r cannot be less than:

$$\frac{m}{2}r^2\dot{\theta}^2=\frac{m}{2}\omega_H^2r^2\left(1-\frac{a^2}{r^2}\right)^2;$$

however, if the potential $V(r)$ does not suffice to give the electron greater kinetic energy, the radial velocity $\dot{r}$ is annulled and the current is interrupted. Consequently

$$\dot{r}=0 \qquad -\frac{2e}{m}V_0(r)=\omega_H^2r^2\left(1-\frac{a^2}{r^2}\right)^2. \tag{10}$$

This is Hull's *limiting value of the potential* V, at the distance r, where the anode current is just cut off by the magnetic field. This limiting value $V_0(r)$ is thus defined without the necessity of determining the distribution of the space charge or the potentials between the anode and cathode —a remarkable fact which discloses the possibility of finding the correct value of the critical potential $V_0(r)$ without considering the space charge.

Reverting to the equation of electron movement in polar co-ordinates r, θ; for θ, the simple result of (7) has been derived; for r,

$$m\ddot{r}=-e\frac{\partial V}{\partial r}+\mu_0 eHr\dot{\theta}+mr\dot{\theta}^2, \tag{11}$$

where the electric, Lorentz and centrifugal forces will be recognized. Replacing $\mu_0 eH$ by the equivalent expression $-2m\omega_H$, it is found that

$$\begin{aligned} m\ddot{r} &= -e\frac{\partial V}{\partial r}-mr\dot{\theta}(2\omega_H-\dot{\theta}) \\ &= -e\frac{\partial V}{\partial r}-mr\omega_H^2\left(1-\frac{a^2}{r^2}\right)\left(1+\frac{a^2}{r^2}\right) \\ &= -e\frac{\partial V}{\partial r}-m\omega_H^2\left(r-\frac{a^4}{r^3}\right) \\ &= -\frac{\partial}{\partial r}\left[+eV+\tfrac{1}{2}m\omega_H^2\left(r^2+\frac{a^4}{r^2}\right)\right]. \end{aligned} \tag{12}$$

The radial acceleration $\ddot{r}$ is accordingly governed by an apparent spherical potential function $P(r)$:

$$m\ddot{r}=-e\frac{\partial P}{\partial r},$$

$$\begin{aligned} eP(r) &= eV(r)+\tfrac{1}{2}m\omega_H^2\left(r^2-2a^2+\frac{a^4}{r^2}\right) \\ &= eV(r)+\tfrac{1}{2}m\omega_H^2r^2\left(1-\frac{a^2}{r^2}\right)^2. \end{aligned} \tag{13}$$

In the function $P(r)$ a constant $m\omega_H^2a^2$ is added in order to reduce $P(a)$ to zero on the filament $r=a$; thus the same function is made to appear as in the energy equation (9). A fact worthy of emphasis is the following:

With the apparent potential $P(r)$, the radial movement of the electron may be studied by means of equation (13) without considering the rotation $\dot{\theta}$ around the filament. These general results are valid in all cases either with or without spacial charge.

3. *Static Space Charge; Critical Potential*

To obtain a potential distribution in a static state, it is necessary to introduce the space charge $\rho(r)$, a function of the radius r and independent of time. Considering the cylindrical symmetry of the system:

$$\Delta V=\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial V}{\partial r}\right)=-4\pi\rho, \tag{14}$$

$$I=2\pi r\rho v_r. \tag{15}$$

The current I, per unit length of filament, is a constant independent of r; v_r is taken from (9) and the following is obtained:

$$\begin{aligned}\frac{\partial}{\partial r}\left(r\frac{\partial V}{\partial r}\right)&=-\frac{2I}{v_r}\\&=-\frac{2I}{\sqrt{-\frac{2e}{m}V(r)-\omega_H{}^2r^2\left(1-\frac{a^2}{r^2}\right)^2}}.\end{aligned} \tag{16}$$

The conditions are the following:

$$\left\{\begin{array}{ll}V(a)=0, & \text{on the filament,}\\ \left(\frac{\partial V}{\partial r}\right)_{r=a}=0, & \text{no saturation.}\end{array}\right. \tag{17}$$

Since the non-linear equation (16) would require detailed discussion, it is preferable to start with the simpler cases where *the current I is zero.* Two methods are available, according to (15):

(A) $\rho\neq 0, \quad v_r=0,$

yielding

$$V_0(r)=-\frac{m}{2e}\omega_H{}^2r^2\left(1-\frac{a^2}{r^2}\right)^2, \tag{18}$$

$$P(r)=0.$$

Expression (18) completely satisfies the two limiting conditions of (17).

(B) $\rho=0, \quad v_r\neq 0;$

hence,

$$V(r)=B\log r+C, \tag{19}$$

corresponding to a definitely electrostatic potential without space charge.

Let us now examine the distributions of the charges and potential in a magnetron when the potential of the anode ($r=R$) is rather low so that no current flows.

The limiting case corresponding to the maximum possible potential on the plate, with no current flowing, is obtained by taking

$$V_0(R)=-\frac{m}{2e}\omega_H{}^2R^2\left(1-\frac{a^2}{R^2}\right)^2, \tag{20}$$

which conforms with (18) or (10); *it is the critical potential.* The density is not zero, but space charges are present throughout the medium between the filament and anode; equation (14) gives their value:

$$\rho_0(r)=\frac{m\omega_H{}^2}{2\pi e}\left(1+\frac{a^4}{r^4}\right). \tag{21}$$

The radial velocity is zero throughout; the electrons follow circular trajectories, centred on the filament. The Lorentz and centrifugal forces are in exact equilibrium with the electrostatic force in equation (11), as is also evident from (13) since the distribution (20), (21) completely annuls $P(r)$.

In the case of a potential $V_0(R)$ below the critical potential, there is obtained a charge distribution (21) from the filament ($r=a$) up to a certain cylinder $r=b$; this particular form of distribution then stops abruptly; the potential distribution then continues in the form of a logarithmic potential (19). By formulating the continuity of the potential and of the field at the cylinder b, the two constants B, C, may be determined by the conditions:

$$-\frac{m}{2e}\omega_H{}^2b^2\left(1-\frac{a^2}{b^2}\right)^2=B\log b+C,$$

$$-\frac{m}{e}\omega_H{}^2\left(b-\frac{a^4}{b^3}\right)=\frac{B}{b}. \tag{22}$$

When the potential $V(R)$ of the anode is progressively lowered, the space charge is correspondingly restricted to a decreasing cylinder b around the filament; and, when $V(R)$ is zero, the space charge disappears.

These results may be explained somewhat differently: assume a magnetron of anode radius b surrounded by a second cylindrical electrode of radius R. With the above distribution, no current

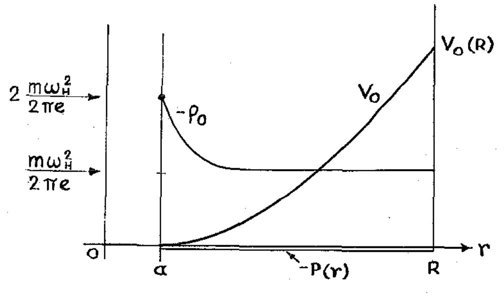

Fig. 1—Critical Condition, I = 0.

passes to the anode b, and an electrostatic field of cylindrical symmetry exists between b and R; the anode b no longer carries any resultant charge because of the equality of the fields (22). It is thus possible to dispense with the intermediate anode b without disturbance of the field.

Fig. 1 illustrates the case of critical potential $V_0(R)$; the different curves represent the space charge density $\rho_0(r)$, the electrostatic potential $V(r)$ and the apparent radial potential $P(r)$.

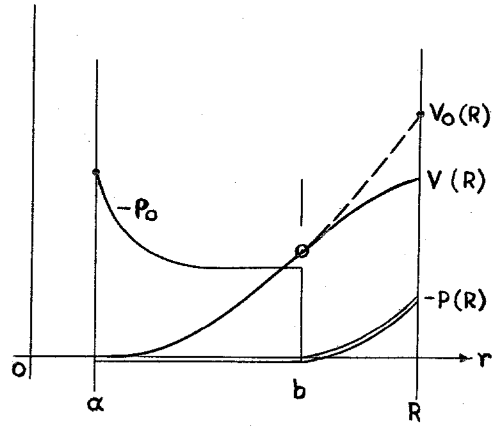

Fig. 2.

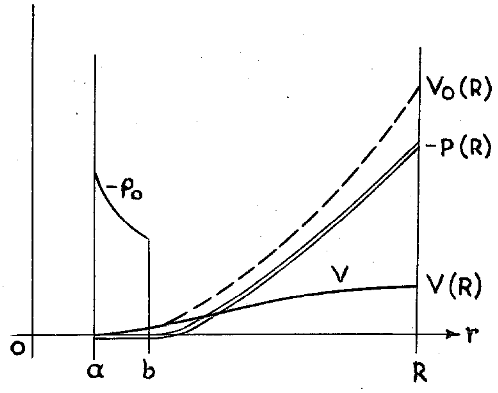

Fig. 3.

Figs. 2 and 3 show the potential distribution of $V(r)$ for various anode potentials lower than the critical value. The apparent potential energy of the electron is $eP(r)$ or $-\epsilon P(r)$, ϵ designating the absolute value of an electron charge. Hence,

$$-P(r) = V_0(r) - V(r), \qquad (23)$$

according to (13) and (18). The behaviour of this function is easily described and is important to recognize inasmuch as the apparent energy P governs the electronic radial movements.

In the critical state (Fig. 1), $-P$ is identically zero. The electrons of the cloud forming the space charge have no radial velocity; but, if some electrons are projected from the cathode into the filament-cathode region with low velocity v_r, these electrons will arrive at the anode with constant radial velocity v_r unimpeded by any obstacle.

The magnetron in the critical state is a system of zero internal resistance. This is confirmed in the following study of the non-zero current conditions.

When the magnetron is below its critical state (Fig. 2 or 3), the apparent potential $-P$ rises between b and R in front of the anode. If electrons are projected from the cathode with low radial velocity, they will reach b at their initial velocity; there, however, they will encounter an impassable potential and will be reflected up to the cathode, returning from b to a with the velocity $-v_r$.

The general characteristics of the problem, simplified in accordance with section 2, are thus outlined. The critical distribution shown in Fig. 1 seems to be exactly that described by Hull [2] in a brief note, for which he claims to have found good experimental evidence from space charge density measurements.

4. *Direct Current Condition Without Saturation*

Since the fundamental equation (16) has just been considered for the various cases where the current is nil, it is now desirable to determine the direct current conditions. Equation (16) will be transcribed, taking as the unknown function the apparent potential $P(r)$ defined in (13) and (23) instead of the electrostatic potential $V(r)$.

$$\frac{\partial}{\partial r}\left(r\frac{\partial V}{\partial r}\right) = \frac{\partial}{\partial r}r\frac{\partial}{\partial r}\Big[P(r)+V_0(r)\Big] = -I\sqrt{-\frac{2m}{e}}\frac{1}{\sqrt{P}}\,;$$

replacing $V_0(r)$ by its value (18):

$$\sqrt{P}\left[-\frac{2m\omega_H{}^2}{e}\left(r+\frac{a^4}{r^3}\right)+\frac{\partial}{\partial r}\left(r\frac{\partial P}{\partial r}\right)\right] = -I\sqrt{\frac{-2m}{e}}. \qquad (24)$$

This equation is rigorous. A solution $P(r)$ such that conditions (17) will be satisfied on the filament yields:

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[2] *Phys. Rev.*, t. 23 (1924), p. 112.

$$P(a)=0, \qquad \left(\frac{\partial P}{\partial r}\right)_{r=a}=0, \text{ on the filament.} \tag{25}$$

The solution of (24) can only be derived approximately; two distinct regions must be considered as limiting cases:

1. Proximity to Filament

The second member remains constant and, on the filament, P is nil; the term in brackets must therefore be infinite, and consequently $\partial^2 P/\partial r^2$ is infinite. The required solution is of the type:

$$P=A(r-a)^n, \tag{26}$$

which gives

$$A^{1/2}(r-a)^{n/2}\left[-\frac{2m\omega_H{}^2}{e}2a+nA(r-a)^{n-1} + aAn(n-1)(r-a)^{n-2}\right]=-I\sqrt{-\frac{2m}{e}}.$$

Taking $n=4/3$, the two first terms are zero, in view of the factor $(r-a)^{n/2}$; the last term remains finite and it is found that:

$$P(r)=\frac{1}{2}\left(\frac{9I}{a}(r-a)^2\right)^{2/3}\left(-\frac{m}{e}\right)^{1/3}, \quad r-a\ll 1. \tag{27}$$

This solution is valid only in the immediate vicinity of the cathode, while $(r-a)$ remains very small. At increasing distances from the cathode, account must be taken of the fact that $\partial P/\partial r$ is no longer zero; and the magnetic term in ω_H must be dealt with. Let us first determine what happens at a short distance from the filament where the magnetic term still remains very small; the problem of the ordinary diode is re-encountered.

The diode without a magnetic field has been dealt with by Langmuir;[3] the potentials V and P are identical and equation (24) reduces to

$$\sqrt{P}\frac{\partial}{\partial r}r\frac{\partial P}{\partial r}=-I\sqrt{-\frac{2m}{e}}. \tag{28}$$

For $r\gg a$, far from the filament, a solution is found in $r^{2/3}$ and the complete solution may be written:

$$P_L=\tfrac{1}{2}(9I\beta^2 r)^{2/3}\left(-\frac{m}{e}\right)^{1/3}, \tag{29}$$

where β is a function of r/a, calculated by Langmuir. (See formula at foot of page.)

Equation (29) presents the same structure as (27) and correspondence is thus established in the vicinity of the filament. The potential P is obtained by replacing $\beta^2 r$ by $(r-a)^2/a$. With r close to a:

$$\beta^2\approx\frac{\left(\frac{r}{a}-1\right)^2}{\frac{r}{a}}. \tag{31}$$

Comparison with (30) shows that this approximation is valid only up to $r=1.25a$; that is, in the immediate vicinity of the filament. This indication gives the limit of validity of (27), which should be replaced by Langmuir's equation (29) when distances beyond the immediate vicinity of the cathode are involved.

Fig. 4 shows the shapes of the various curves.

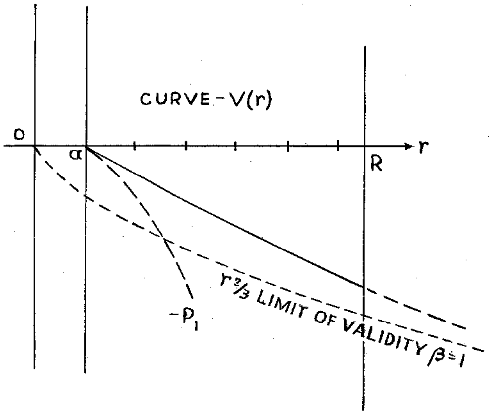

Fig. 4—Diode without Magnetic Field—Langmuir Curve.

$\frac{r}{a}$	1	1.25	1.5	1.75	2	2.5	3	4	5	6	7	8	9	10	15	∞
β^2	0	0.045	0.116	0.2	0.275	0.405	0.512	0.665 ↓	0.755	0.818 ↓	0.867	0.902 ↓	0.925	0.94 ↓	0.978	1

(30)

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[3] *Phys. Rev.*, t. 2 (1913), p. 458. An approximate solution may be found:

$$P=\frac{1}{2}\left(-\frac{m}{e}\right)^{1/3}(9I)^{2/3}\frac{(r-a)^{4/3}}{r^{2/3}};$$

it yields correct results for very small or very large r; the error is about 20% near $r=5a$.

2. Distant from Filament

At a considerable distance from the filament the Langmuir equation gives low values for the term $(\partial/\partial r)r(\partial P/\partial r)$; contrariwise, the magnetic term within the brackets of (24) increases indefinitely. A moment therefore arrives when this first term becomes preponderant. At the limit, the second term may be neglected and the first term kept. An asymptotic solution P_ω, valid at a great distance, is:

$$P_\omega(r) = -I^2 \frac{e}{2m\omega_H{}^4}\left(r+\frac{a^4}{r^3}\right)^{-2}, \qquad r \gg a \qquad (32)$$

It is now necessary to discuss the junction of these two extreme cases with a view to ascertaining the corresponding values of r and obtaining the form of function $P(r)$.

Comparing the equations, an expression $-eI/m\omega_H{}^3$ appears, homogeneous to a certain length L squared; the following gives an indication of the order of magnitude:

$\frac{e}{m} = 5.3 \times 10^{17}$ (E.S.C.G.S.)

$I = 3 \times 10^6 J$ (J measured in milliamperes; I in E.S.C.G.S. units).

Calculating ω_H according to (5) and H in gausses:

$$L^2 = -\frac{eI}{m\omega_H{}^3} = 2.3 \cdot 10^3 \frac{J}{H^3}. \qquad (33)$$

The role played by the characteristic length L is very important and has now to be discussed.

First the condition $r > L$ must be satisfied in order to justify use of the solution (32); this necessitates:

$$\frac{\partial}{\partial r} r \frac{\partial P_\omega}{\partial r} \ll -\frac{2m\omega_H{}^2}{e}\left(r+\frac{a^4}{r^3}\right).$$

Neglecting a, this condition reduces to

$$r^2 \gg L^2.$$

For weak fields, scarcely disturbing the diode, the length L is much greater than the dimensions of the bulb; if the field increases, however, the length L decreases considerably to the order of magnitude of the interior dimension of the bulb and may even drop to very low values; for some hundreds of gausses. L is of the order of hundredths of mm.

The length L then gives the magnitude of the distance where the Langmuir solution P_L (always valid in the immediate vicinity of the filament) joins the solution P_ω which is valid at a great distance.

Taking, as a criterion of the distance of coincidence, the condition:

$$P_L(r) = P_\omega(r),$$

then

$$\tfrac{1}{2}(9I\beta^2 r)^{2/3}\left(-\frac{m}{e}\right)^{1/3} = -I^2 \frac{e}{2m\omega_H{}^4}\left(r+\frac{a^4}{r^3}\right)^{-2}; \qquad (34)$$

hence

$$9\beta^2 r\left(r+\frac{a^4}{r^3}\right)^3 = L^4. \qquad (35)$$

If the length L is less than the diameter of the filament, the result is approximately

$$9\beta^2 r(2a)^3 = L^4;$$

and if L is definitely greater than a, (35) reduces to

$$9r^4 = L^4, \qquad r = L\frac{\sqrt{3}}{3}.$$

The curve representing the apparent potential $P(r)$ is consequently known by the expressions P_L (for $r \ll L$) and P_ω (for $r \gg L$); it can, in any case, be plotted approximately. Fig. 5 shows curves for various values of L between the cathode ($r = a$) and the anode ($r = R$).

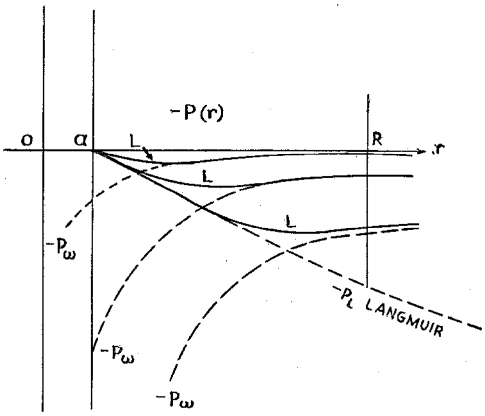


Fig. 5.

If the anode radius R is appreciably greater than the length L, the formula $P_\omega(R)$ of (32) gives the anode voltage (calculated from the critical voltage $V_0(R)$; if, however, the length L is very great, the magnetic field being weak, Langmuir's curve P_L is used. Fig. 6, accordingly, shows the magnetron characteristic; the resistance $\partial V/\partial I$ is zero in the vicinity of the critical point (section 3).

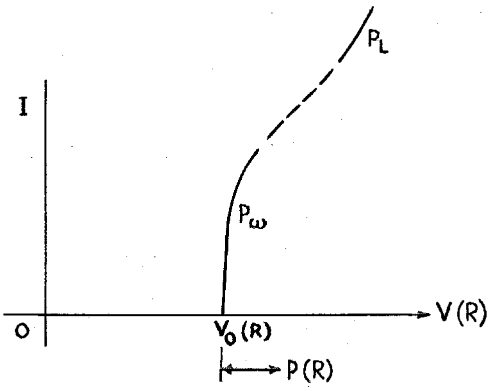


Fig. 6—Magnetron Characteristic.

Reverting to the curves of Fig. 5, it should be noted that the electrons, after leaving the filament ($r=a$), first reach the Langmuir region and then travel towards $r=L$ through a region of low apparent potential energy, thereafter rebounding (approaching the anode) towards higher potential energies only slightly below the potential energy of the cathode. The expression $-P(r)$ represents, but for the factor ϵ, the apparent potential energy of the electrons, controlling their radial movements (equation 13). The speed of rotation around the filament is defined by (7). The curves $-P(r)$ show that the electrons are accelerated from a to L and retarded from L to R. The space charge thus is increased in the second region; close to the filament, Langmuir's space charge applies and, at a great distance, the constant space charge of (21) applies approximately:

$$r \gg L, \qquad \rho = \frac{m\omega_H^2}{2\pi e}. \tag{36}$$

A more detailed study would require calculation of the junction of the curves in the region L. The following, however, is pertinent:

The electronic paths start radially from the filament; they are slightly curved in the region $r<L$ and then turn around the filament for $r>L$, as shown in Fig. 7. This can be understood readily from the following considerations: Let v_r and v_θ be the radial and rotational components of electronic velocity; equations (15) and (7) yield:

$$I = 2\pi r\rho v_r$$

$$v_\theta = r\dot{\theta} = r\omega_H\left(1-\frac{a^2}{r^2}\right).$$

Instead of computing the ratio v_r/v_θ, let us calculate

$$\frac{\rho v_r}{\rho_0 v_\theta} = \frac{I}{2\pi r^2\rho_0\omega_H\left(1-\frac{a^2}{r^2}\right)}$$

$$= \frac{eI}{m\omega_H{}^3 r^2\left(1-\frac{a^2}{r^2}\right)\left(1+\frac{a^4}{r^4}\right)} = \frac{L^2}{(r^2-a^2)\left(1+\frac{a^4}{r^4}\right)},$$

ρ_0 being the space charge density (21) in the region $r \gg L$. Neglecting the radius a of the cathode, as a first approximation, it is seen that the ratio $\rho v_r/\rho_0 v_\theta$ equals 1 when $r=L$, which proves that v_r and v_θ are of the same order of magnitude at a distance L from the filament.

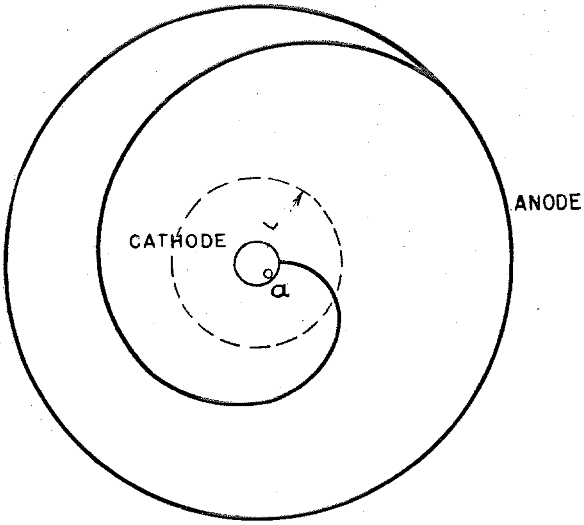


Fig. 7.

5. *Study of the Transition Region L*

The intermediate region may be studied either by proceeding from Langmuir's solution P_L or from the magnetic solution P_ω. In any case a series of approximations will be obtained.

Commencing with Langmuir's distribution P_L, valid for ω_H nil, the solution is developed in the form

$$P = P_L + \alpha P_1 + \alpha^2 P_2 \cdots; \qquad \alpha = -\frac{2m}{e}\omega_H{}^2. \tag{37}$$

The parameter α is assumed to be small. Introducing this series into (24), a successive series of equations is derived by developing the radical $\sqrt{P}$ in accordance with usual methods and assuming $r \gg a$; terms independent of α are:

$$\sqrt{P_L}\frac{\partial}{\partial r}r\frac{\partial}{\partial r}P_L = -I\sqrt{-\frac{2m}{e}}\,;$$

terms in α are:

$$\sqrt{P_L}\left[\frac{P_1}{2P_L}\left(\frac{\partial}{\partial r}r\frac{\partial}{\partial r}P_L\right)+r+\frac{\partial}{\partial r}r\frac{\partial}{\partial r}P_1\right]=0; \qquad (38)$$

terms in α^2 are:

$$\sqrt{P_L}\left[\left\{\frac{1}{2}\frac{P_2}{P_L}-\frac{1}{8}\left(\frac{P_1}{P_L}\right)^2\right\}\frac{\partial}{\partial r}r\frac{\partial}{\partial r}P_L + \frac{P_1}{2P_L}\left(r+\frac{\partial}{\partial r}r\frac{\partial}{\partial r}P_1\right)+\frac{\partial}{\partial r}r\frac{\partial}{\partial r}P_2\right]=0.$$

At the different orders, linear differential equations with second member must always be solved, the general type being:

$$\frac{\partial}{\partial r}r\frac{\partial}{\partial r}P_k-\frac{2}{9r}P_k=F_k(r), \qquad (39)$$

where $F_k(r)$ is a function which is known from the preceding approximations. Expression (39) is based on the fact that the coefficient of P_k is always $\frac{1}{2}P^{-1}{}_L(\partial/\partial r)r(\partial/\partial r)P_L$, which gives $-2/9r$ when r is greater than $10a$, making it possible to insert $\beta=1$ in Langmuir's equation (29). The second members F_k have the following values:

$$F_1=-r,$$

$$\begin{aligned}F_2&=-\frac{1}{8}\left(\frac{P_1}{P_L}\right)^2\frac{\partial}{\partial r}r\frac{\partial}{\partial r}P_L + \frac{P_1}{2P_L}\left(r+\frac{\partial}{\partial r}r\frac{\partial}{\partial r}P_1\right)\\ &=\frac{P_1}{2P_L}\left[P_1\frac{1}{9r}+r+\frac{\partial}{\partial r}r\frac{\partial}{\partial r}P_1\right]\\ &=\frac{1}{6r}\frac{P_1^2}{P_L}.\end{aligned} \qquad (40)$$

The last transformation, in F_2, is obtained with the aid of equation (39) in terms of P_1.

Equations (39), in general, admit solutions without the second member

$$P_k=r^{\pm\sqrt{2}/3},$$

such that the general solution without the second member is

$$P_k=A_kr^{\sqrt{2}/3}+B_kr^{-\sqrt{2}/3}, \qquad (41)$$

which contains two arbitrary constants. It is necessary to add a particular solution P_{k1} from the equation having the second member and to adjust the whole so as to satisfy the conditions imposed at the limit: P and $\partial\rho/\partial r$ zero on the filament $r=a$.

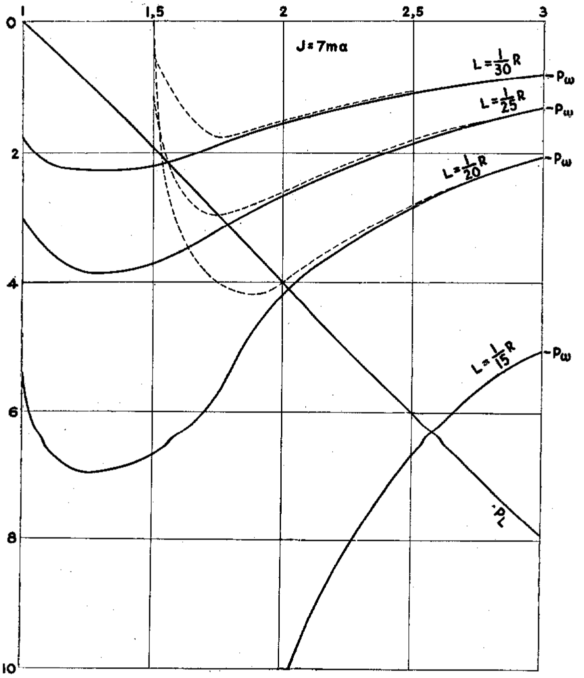


Fig. 8.

In fact, if particular solutions P_{k1} of the equation with the second member be found of the form $r^n (n>1)$ satisfying the conditions imposed, the step involving solutions without the second member can be omitted (41).

For the first approximation, equation (39) becomes

$$\frac{\partial}{\partial r}r\frac{\partial}{\partial r}P_1-\frac{2}{9r}P_1=-r. \qquad (42)$$

The particular solution is:

$$P_1=-\frac{9}{34}r^2.$$

For the second approximation:

$$\begin{aligned}\frac{\partial}{\partial r}r\frac{\partial}{\partial r}P_2-\frac{2}{9r}P_2&=\frac{1}{6r}\frac{P_1^2}{P_L}\\ &=\frac{27}{34^2}\left(-\frac{e}{m}\right)^{1/3}\frac{r^{7/3}}{(9I)^{2/3}},\end{aligned} \qquad (43)$$

which may be resolved with a function

$$P_2=Kr^{10/3}, \qquad K=\frac{2.17}{J^{2/3}}. \qquad (44)$$

Continuing the process step by step, the terms in αP, $+\alpha^2 P_2 \cdots$ of (37) give progressively the actual curve P starting with Langmuir's approximation for values of r between a and L.

The second series of approximations in the region $r > L$ proceeds from the magnetic solution P_ω (32). It appears in the form of a development in powers of $1/\alpha$:

$$P_\omega = +\left(\frac{I}{\omega_H}\right)^2 \frac{1}{\alpha r^2}, \quad r \gg a, \quad \alpha = -\frac{2m}{e}\,\omega_H{}^2,$$

$$P = P_\omega + \frac{1}{\alpha^2}\,Q_2 + \frac{1}{\alpha^3}\,Q_3 + \cdots. \tag{45}$$

Introducing this expression in (24) and developing in powers of $1/\alpha$:

$$\begin{aligned}\frac{1}{\sqrt{\alpha}}\,\frac{I}{\omega_H r}\Bigg\{1 - \frac{Q_2}{2\alpha}\left(\frac{\omega_H r}{I}\right)^2 &\\ + \frac{1}{2\alpha^2}\left[-Q_3\left(\frac{\omega_H r}{I}\right)^2 + \tfrac{1}{4}Q_2{}^2\left(\frac{\omega_H r}{I}\right)^4\right]\cdots\Bigg\} &\\ \times\Bigg\{-\alpha r + \frac{4}{\alpha r}\left(\frac{I}{\omega_H r}\right)^2 + \frac{1}{\alpha^2}\,\frac{\partial}{\partial r}\,r\,\frac{\partial Q_2}{\partial r} &\\ + \frac{1}{\alpha^3}\,\frac{\partial}{\partial r}\,r\,\frac{\partial Q_3}{\partial r}\cdots\Bigg\} &= -I\sqrt{-\frac{2m}{e}}.\end{aligned}$$

Regrouping:

$$\begin{aligned}\Bigg\{1 - \frac{Q_2}{2\alpha}\left(\frac{\omega_H r}{I}\right)^2 &\\ + \frac{1}{2\alpha^2}\left[-Q_3\left(\frac{\omega_H r}{I}\right)^2 + \tfrac{1}{4}Q_2{}^2\left(\frac{\omega_H r}{I}\right)^4\right]\Bigg\} &\\ \times\Bigg\{1 - \frac{4}{\alpha^2 r^2}\left(\frac{I}{\omega_H r}\right)^2 - \frac{1}{\alpha^3 r}\,\frac{\partial}{\partial r}\,r\,\frac{\partial Q_2}{\partial r} &\\ - \frac{1}{\alpha^4 r}\,\frac{\partial}{\partial r}\,r\,\frac{\partial Q_3}{\partial r}\Bigg\} &= 1. \end{aligned} \tag{46}$$

Separating the successive terms in $1/\alpha$, $1/\alpha^2 \cdots$, there are obtained in terms of $1/\alpha$

$$Q_2 = 0$$

in terms of $1/\alpha^2$

$$-\frac{1}{2}\left(\frac{\omega_H r}{I}\right)^2 Q_3 - \frac{4}{r^2}\left(\frac{I}{\omega_H r}\right)^2 = 0,$$

$$Q_3 = -\frac{8}{r^6}\left(\frac{I}{\omega_H}\right)^4, \tag{47}$$

etc.; the solution Q_3 tends towards zero when r increases indefinitely; the limiting value P_ω of P at a great distance is thus derived in accordance with (45).

In order to obtain a concept of the practical value of these developments, it is necessary to draw curves based on numerical values corresponding to types of magnetrons actually constructed.

Such an attempt has been made with the following numerical data:

cathode—radius $a = 0.005$ cm,
anode—radius $R = 0.1$ cm,
current $J = 7$ milliamperes.

The results of the calculations are shown in Fig. 8. Abscissae are the ratios r/a of the radius r to the cathode radius a: they run from 1 to 3 and relate therefore only to the vicinity of the filament; the ratio R/a for the anode equals 20. As ordinates, the quantities $-P$ have been chosen, and the conditions are the same as on Figs. 4 or 5. Langmuir's curve P_L gives the potential distribution near the filament, while the magnetic curve P_ω yields the potential at greater distances. The curves P_ω have been drawn for different values of L, corresponding to different magnetic fields; the corrections $\alpha P_1 + \alpha^2 P_2$ to P_L (37) have proved practically negligible. On the other hand, the Q_2 correction to P_ω (45) must be taken into account and gives the dotted curves on Fig. 8; further terms Q_3, $Q_4 \cdots$ would be necessary to join smoothly the two branches P_L and P_ω near their intersection.

6. *Conclusions*

This study of the magnetron, in its static condition, has been pursued for the first time with strict regard to the influence of the space charge.

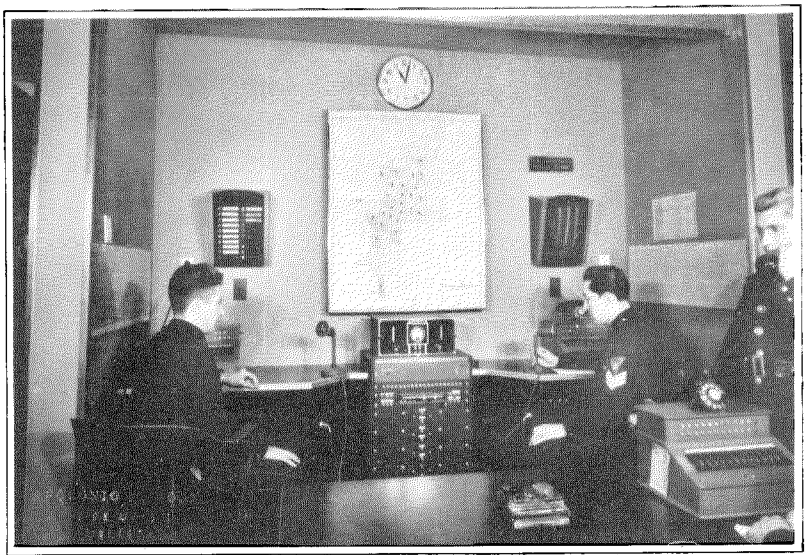
The speed of rotation of the electrons around the filament results from the magnetic field (7); hence, an apparent radial potential $P(r)$ may be defined, governing the radial movements of the electrons (13). This potential $P(r)$, at distance (r), is equal to the real potential $V(r)$ less the critical potential $V_0(r)$, which would just prevent the electrons from reaching an anode placed at r (23). The apparent potential $P(r)$ may be studied methodically; in the vicinity of the filament, it approaches Langmuir's result (eq. 29, diode without magnetic field); as the distance (33) becomes of the order of

$$r = L = \sqrt{-\frac{eI}{m\omega_H{}^3}},$$

the potential P departs from Langmuir's curve and then corresponds with a function $P_\omega(r)$ typical of the magnetron. Under certain conditions, in the region of correspondence $(r=L)$, a maximum potential may be obtained such that the electronic energy $eP=-|e|P$ is a minimum. The disposition of the apparent potential P in a magnetron under these conditions then becomes analogous to that found in a Barkhausen valve with a strongly positive grid and a moderate anode potential. It is thus possible to foresee that, under prescribed conditions, oscillations could be maintained in the magnetron.

The study of these oscillations is practicable but demands highly rigorous analysis. It would probably also be necessary to study the magnetron when functioning at saturation. It should be emphasized that the saturated condition is conducive to obtaining maximum apparent potential P.

Police Radio in Mexico



Dispatchers' Equipment and Dispatchers Who Control the Operations of the Radio Patrol. The various patrol sectors of the city are shown on a lighted map which also indicates the positions of patrol cars.

A TWO-WAY police radio telephone system, serving an area of approximately fifty square miles, was inaugurated November 28, 1940 in Mexico City.

The headquarters transmitter (XBLP) is installed in the "Caballero Alto" tower of Chapultepec Castle, on Chapultepec Hill, dominating the Valley of Mexico. A control system and a special PBX are located three miles away at Police Headquarters. Calls for patrol cars, routed through this PBX to the dispatchers, may be made from any point in the city by dialing 06. A second PBX serves Police Headquarters, police booths and street telephone boxes.

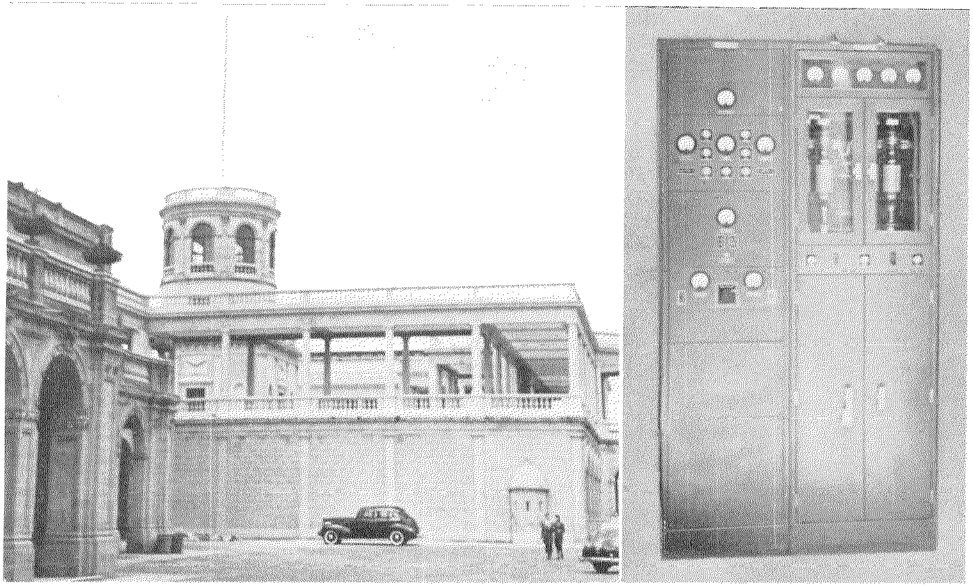
The output of nine strategically located 28-A Receivers, connected by telephone lines, is brought to Police Headquarters. Messages are reproduced by a loudspeaker adjacent to the dispatchers.

The system was engineered and supplied by the International Standard Electric Corporation, New York. In view of its successful operation, resulting in marked crime reduction, it will be expanded in the near future.

Right—Mobile Equipment Lined Up in Patio of Chapultepec Castle. It consists of twenty 1941-model Buicks furnished with 228-A Mobile Radio equipment. The automobiles of the Chief of Police and the Governor of Mexico City are similarly equipped.

Left—Police Officer Operating Car Radio Equipment.

Left—Major Alvaro Basail, Chief of the Radio Patrol. Under his leadership the "Consejo Cívico de Seguridad Pública," by public subscription, acquired the funds necessary for the purchase of the Police Radio System. Right—Police Headquarters PBX With Twenty Trunks.



Left—"Caballero Alto" Tower of Chapultepec Castle Showing Mast and Antenna of the Headquarters Radio Transmitter of the Mexico City Police Radio System. Right—16-B Ultra-Short Wave Radio Transmitter and 88-A Amplifier Installed in the Base of the Tower, "Caballero Alto," of Chapultepec Castle. Output: 500 Watts.

Selenium Rectifiers for Closely Regulated Voltages

By J. E. YARMACK, S.B. in E.E.

International Telephone & Radio Manufacturing Corporation, New York, N. Y.

This article supplements a previous publication[1] *in this journal and describes novel applications of Selenium Rectifiers. The sections dealing with static and dynamic load characteristics of bridge connected Selenium Rectifiers, and easily attainable close voltage control, were published in the September 1941 issue of* ELECTRONICS. *An additional section discusses application of Selenium Rectifiers in another type of circuit now being widely used in automatic Battery Chargers; also, the application of these rectifiers in Battery Eliminators for telephone and telegraph services.*

RECTIFICATION of alternating current power to direct current power is becoming increasingly common in the United States due to the prevalence of alternating current mains supplies combined with steadily increasing direct current applications. Many types of equipment are employed to furnish direct current power, but the convenience, economy and simplicity of Selenium Rectifiers make them almost indispensible for numerous applications. In many cases the source of direct current must provide a substantially constant output voltage under varying load and power supply conditions, a type of service for which Selenium Rectifiers are ideally suited.

The inherent static voltage regulation of Selenium Rectifiers is in the neighborhood of 10 to 20 percent. Its exact value depends upon the degree and nature of loading, the type of rectifier circuit and the effective rectifying area of the Selenium Rectifier plates employed. Moreover, when required, measures can be adapted for achieving extremely close regulation of the order of 2 percent. Such a scheme is described in detail hereinafter. In designing Selenium Rectifiers to give the required rectified current output, the engineer must select the proper size of plates and if necessary determine their number in parallel to provide adequate current capacity, compute the alternating current voltage to be impressed on the rectifier elements and analyze various factors involved in the selected type of circuit, such as the character of the load, duty cycle, ambient temperature and cooling requirements.

Design of Selenium Rectifier

The size and, when necessary, the number of rectifier plates in parallel are determined by examination of ratings of all available selenium plates. The required alternating current voltage to be impressed upon the rectifier elements, V_{ac}, is usually computed by the following formula:

$$V_{ac}=k_1V_{dc}+k_2nv, \tag{1}$$

and the number of plates in series by the formula:

$$n=1.1k_1V_{dc}/(V_p-1.1k_2v) \tag{2}$$

where k_1 is the form factor, that is, the ratio of the effective or root-mean-square value of the wave to the average value of rectified voltage wave,

V_{dc} is the required direct current output voltage,

k_2 is the circuit factor and is 2 for the single phase bridge circuit or 1 for the center tap circuit,

V_p is the maximum safe permissible root-mean-square voltage per plate, and

v is the voltage drop per Selenium Rectifier plate in root-mean-square values.

The ten percent or 1.1 factor is the voltage variation factor and is selected upon the designer's consideration of possible alternating current input voltage fluctuations.

The quantity v plays a most important role in the performance of the Selenium Rectifier and changes slightly during the first 10,000 hours of fully loaded service, after which it remains constant. Quantitatively, the voltage drop of the Selenium Rectifier plate may vary from 0.9 to 1.3

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[1] "Selenium Rectifier Characteristics, Applications and Design Factors," Carole A. Clarke, *Electrical Communication*, Vol. 20, No. 1.

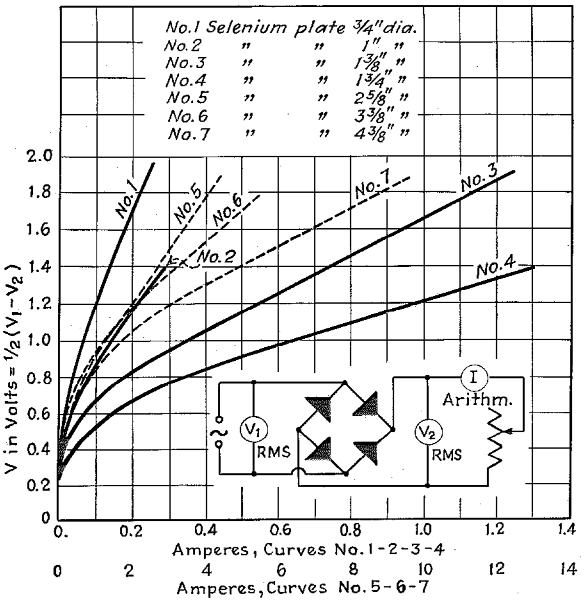

Fig. 1—Rectification Characteristics of Seven Basic Rectifier Plates.

volts for the rated plate current. At ambient temperatures less than 35 degrees C., its value increases but at ambient temperatures higher than 35 degrees C. its value slightly decreases. For practical use in designing rectifiers the relation of the quantity v to the arithmetical values of the rectifier output current have been determined experimentally for seven basic sizes of selenium plates and are portrayed in Fig. 1.

In designing the teletype rectifier unit (Figs. 2, 3 and 4), capable of delivering a dual output of 6 amperes, 120 volts each, the No. 7 Selenium Rectifier plate, $4\frac{3}{8}$ inches in diameter and rated at 4 amperes for the single phase bridge circuit, was selected inasmuch as it provides an ample safety factor for extended current rating. The safe maximum reverse voltage rating of this plate is 14 volts rms. Inasmuch as the complete circuit calls for a 14-volt drop between the output terminals of the rectifier and the output terminals of the unit, the alternating voltage into the rectifier can be computed by equation (1). Hence, on the basis of an operating plate rating for this case of only 3 amperes at 134 volts:

$$V_{dc} = (190 - 2 \times 15 \times 0.3)/1.15 = 157 \text{ volts.}$$

The voltage regulation therefore is $(157-134)/134 = 0.172$ or 17.2 percent.

Static and Dynamic Regulation

In the application of rectifier equipment two types of output voltage regulation are of interest and must be considered when designing power supply units for various purposes. These are the static and dynamic regulation characteristics. The static regulation characteristic, the compu-

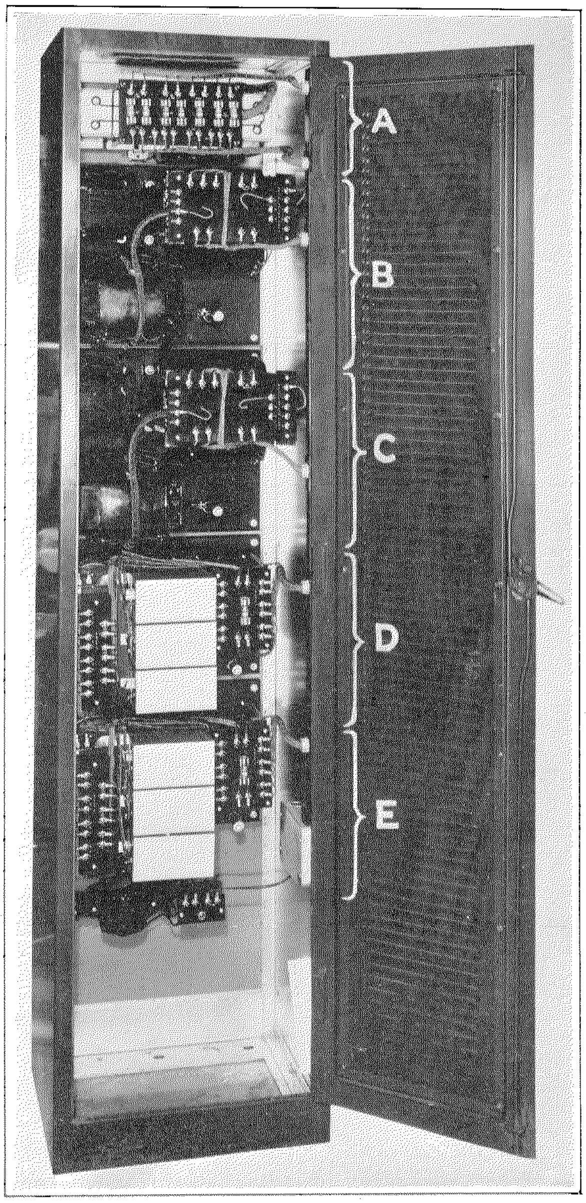

*Fig. 2—Teletype Rectifier Unit. (A) Metering and Switching Panel. (B, C) Transformer Panels. (D, E) Rectifier and Filter Panels.**

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* Equipment illustrations in this article are published by courtesy of the Power Equipment Company, Detroit, Mich.

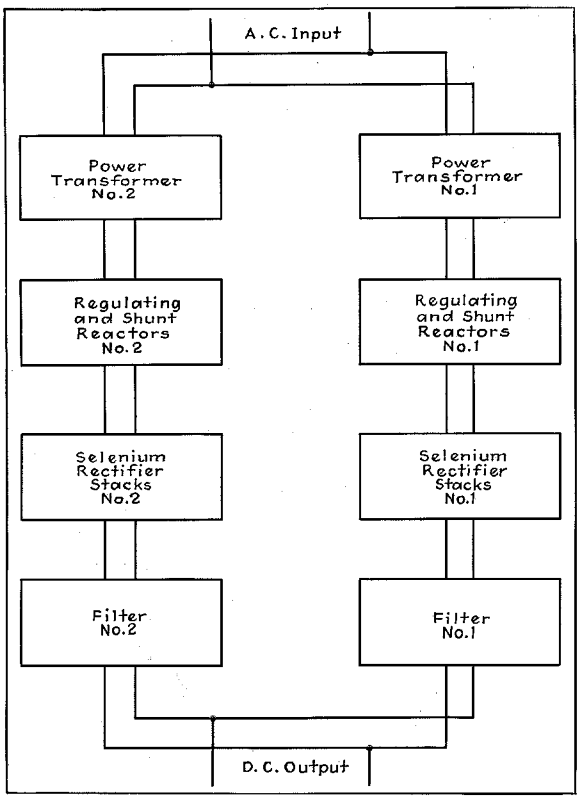
A.C. Input
Power Transformer No.2
Power Transformer No.1
Regulating and Shunt Reactors No.2
Regulating and Shunt Reactors No.1
Selenium Rectifier Stacks No.2
Selenium Rectifier Stacks No.1
Filter No.2
Filter No.1
D.C. Output

Fig. 3—Block Diagram of Teletype Rectifier of Fig. 2.

tation of which is exemplified above, represents the relation of the rectifier output voltage to the output current and is plotted from D'Arsonval meter readings of the current and voltage for a series of steady-state conditions from no load to full load (Fig. 5).

The dynamic regulation characteristic also represents the relation between the rectifier output voltage and current, but is obtained while keying or interrupting the load or a combination of loads at varying rates by measuring the instantaneous voltage and current values (Fig. 6).

The best method of measuring this type of regulation is with the oscillograph. Current and voltage values are photographed simultaneously with a 60-cps wave used for time calibration. Measurements of the ordinates of these characteristics provide instantaneous values from which the regulation may be computed.

In certain applications of rectifiers, such as those in which the load is keyed, dynamic regulation may be of great importance. When several load circuits are operated from a common source it is usually important that none of the individual output circuits should interfere with any of the others.

The variation in output voltage of a typical regulated circuit of the type described below, with a keyed load alone, and with the keyed load superimposed upon fixed loads of different values is shown in Fig. 6. It will be noted that the voltage variation decreases with an increase in the magnitude of the fixed load. Fig. 5 shows

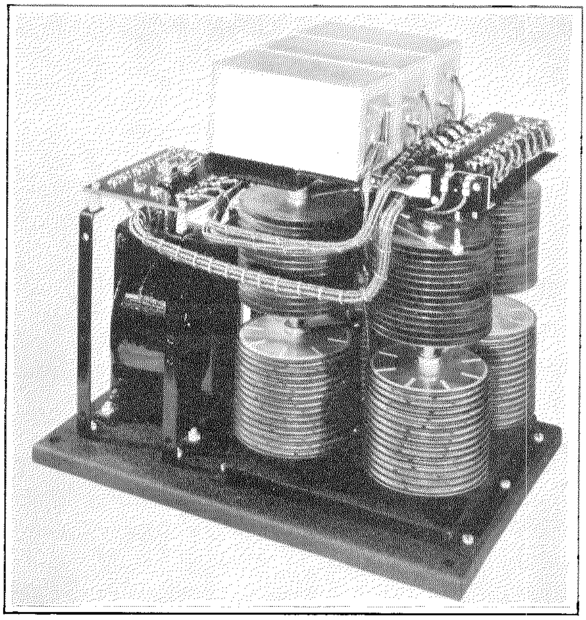

Fig. 4—A Teletype Rectifier Showing Filter and Four Selenium Stacks Connected for Two Separate Bridge Units. Output is 6 Amperes at 120 Volts.

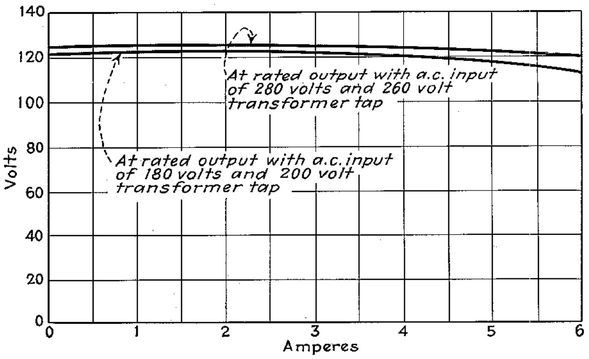

Fig. 5—Static Characteristics of 6-Ampere, 120-Volt Rectifier, Corrected by Regulating and Shunt Reactors.

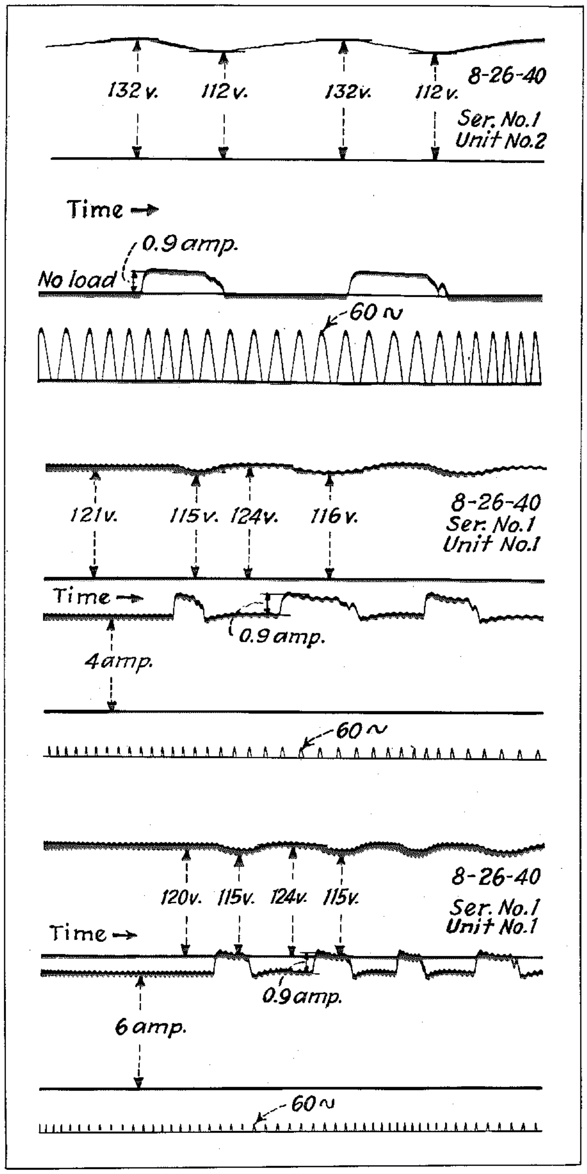

Fig. 6—Dynamic Characteristics of 6-Ampere, 120-Volt Rectifier Under Three Different Load Conditions.

the static regulation characteristics of the same type of rectifier from no load to full load. From these characteristics it can be seen that the regulation is less than 5 percent throughout the operating range even though the applied line voltage of 280 volts is in excess of the rated input voltage of 260 volts for the transformer tap used in making this test.

The static voltage output characteristics of another rectifier under various ambient temperatures are illustrated in Fig. 7, and a rear view of the rectifier is shown in Fig. 8. The output voltage, while lower at sub-zero temperatures than at normal room temperature, is nevertheless remarkably constant throughout the rated current range. The four volt lower output voltage of this unit at minus 5° C. is due to increase of the *v* value.

As compared to mercury vapor and gas filled hot cathode tube type rectifiers, Selenium Rectifiers have relatively high internal forward resistance. In order to apply dry plate rectifiers to devices requiring constant applied voltage, it is often necessary to provide means for com-

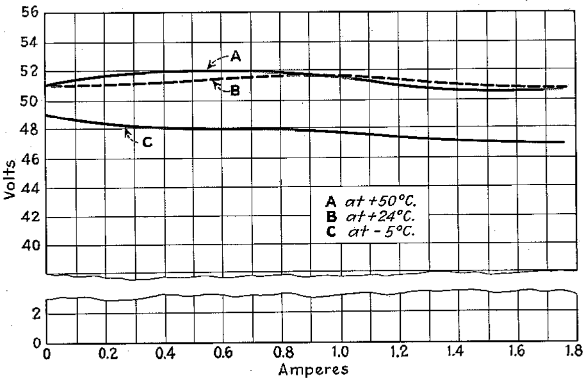

Fig. 7—Characteristics of Strowger Switch Rectifier: 0.75-Ampere Continuous, 1.75-Ampere Intermittent Load.

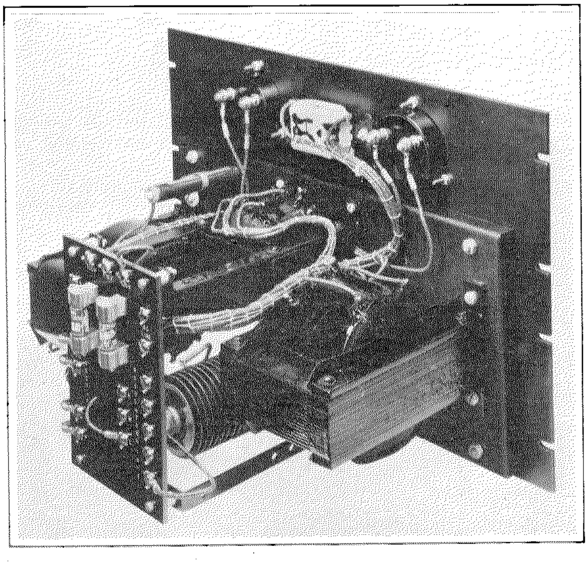

Fig. 8—Rear View of Selenium Rectifier for Strowger Switch Operation. Characteristics are Given in Fig. 7.

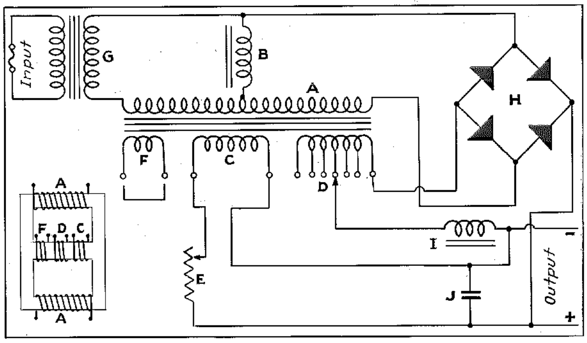

Fig. 9—Schematic Showing Principle of Controlled Output Voltage by Regulating and Shunt Reactors.

pensating for the internal resistance of the rectifier and for the transformer and filter reactor voltage drops by means of devices controlling the alternating current voltage applied to the rectifier.

A large variety of methods of voltage regulation has been developed and used. Some of them are universally successful; others are effective only within a limited field. Certain types of regulating circuits use gas or vacuum tube characteristics while other circuits employ saturable reactors to accomplish the same purpose. The circuit illustrated in Fig. 9 and described here as an example of such compensation utilizes two iron core reactors to regulate the voltage applied to the rectifier and requires no rectifier elements other than the main or power ones.[2]

Circuit for Voltage Regulator

In the simplified typical circuit of Fig. 9 the control elements consist of a direct current controlled saturable three-legged reactor and an alternating current controlled saturated reactor, each having a separate core with no magnetic relation to the other. These two reactors are so proportioned that, for the rectifier with which they are used, the output voltage is held within close limits from no load to full load despite line voltage variations. By proper design of the regulating coils it is possible to arrange a circuit to give either a rising, a flat, or a dropping static voltage characteristic.

The basic circuit of Fig. 9 consists of a series reactance, *A*, and a shunt reactance, *B*, connected between the transformer secondary winding, *G*, and the input terminals of the rectifier, *H*. The value of the series impedance is controlled by two direct current windings, *C* and *D*, associated with the output circuit of the rectifier. One of the windings, *D*, is connected in series with the load circuit and the other winding, *C*, is connected in parallel with the load circuit. The amount of current that flows through the shunt direct current winding, *C*, is controlled by means of the variable resistor, *E*, in the circuit, permitting adjustment of the no load output voltage. Both direct current windings are connected additively.

The shunt reactor, *B*, serves to increase the voltage drop in the series reactor, *A*, under light loads and thereby to reduce the voltage applied to the rectifier stack and to keep the light load voltage within the desired limits. Reactor *B* is

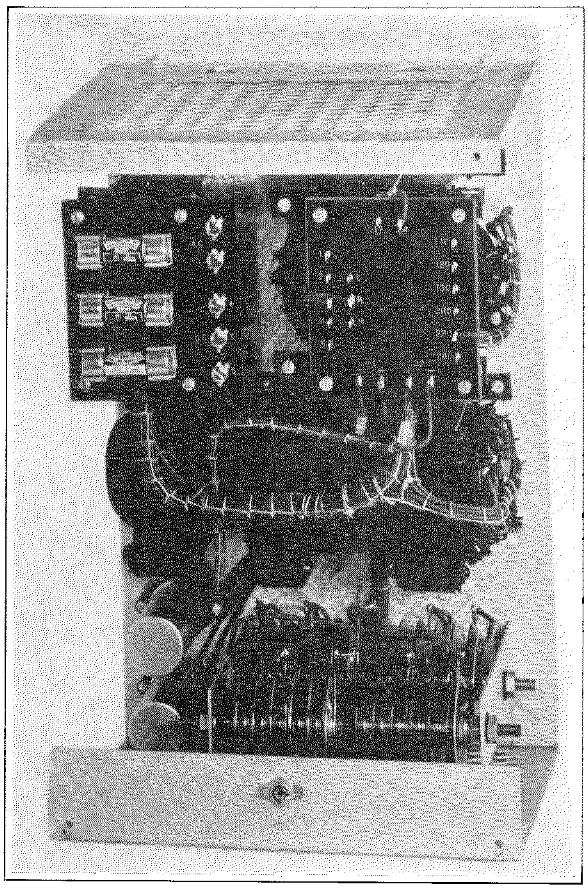

Fig. 10—Telephone Battery Eliminator: 2.4 Ampere, 17/24 Volt Rating.

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[2] U. S. Patent No. 2,182,666.

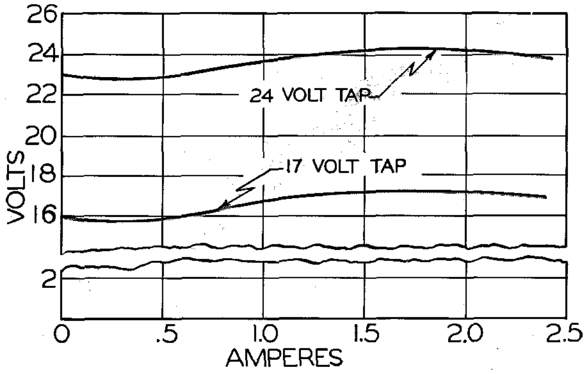

Fig. 11—Performance Characteristics of the Telephone Battery Eliminator Illustrated in Fig. 10.

also effective in compensating for line voltage variation. An increase in line voltage results in increased current in this coil and increased voltage drop in reactor *A*, so that the voltage applied to the rectifier is held approximately constant.

The series direct current winding, *D*, affects the output voltage characteristic under all load conditions and serves the purpose of lowering the impedance of the series alternating current winding, *A*, as the output current increases by increasing saturation of the core of the regulating coil. The decrease in the series reactance causes a net increase in the alternating current voltage applied into the rectifying elements, thereby maintaining the output voltage relatively constant over the rated output current range. By selecting the proper tap on the winding, *D*, the shape of the characteristic can be varied over a wide range and can be made to give a higher voltage at heavy loads than at lighter loads.

By increasing the number of turns in the direct current series winding, *D*, the reactance *A* may be decreased and the alternating current input voltage to the rectifying elements may be increased. This offers a convenient means of compensating for the increase in resistance of the rectifier stack or stacks that may take place as they reach their final condition upon full aging. The short circuited winding, *F*, usually provided, serves the purpose of eliminating the pulsating fluxes, due to the unbalanced ampere-turns in the two halves of winding *A*, in the center leg of the three-legged regulating reactor.

The alternating current taken by the rectifier stacks when the direct current load is disconnected stabilizes within one minute with the selenium type plates. This stabilization period with other types of dry plate rectifiers may be anywhere from a half hour to six hours and usually affects the light load portion of the output voltage characteristic.

Battery Chargers and Eliminators

The foregoing method of regulating the rectified output voltage frequently is adapted to automatic battery chargers and battery eliminators. Fig. 10 shows the telephone battery eliminator. The electric circuit of this unit is essentially the same as portrayed in Fig. 9 except that it utilizes a two section filter, comprising one pair of reactors and one pair of high capacitance condensers for the purpose of insuring a low hum level at the output. The ripple component at full load is less than 25 millivolts. The output voltage characteristics (Fig. 11) illustrate the fact that, notwithstanding greater voltage drop in component parts of the circuit, slightly higher output voltages can be obtained

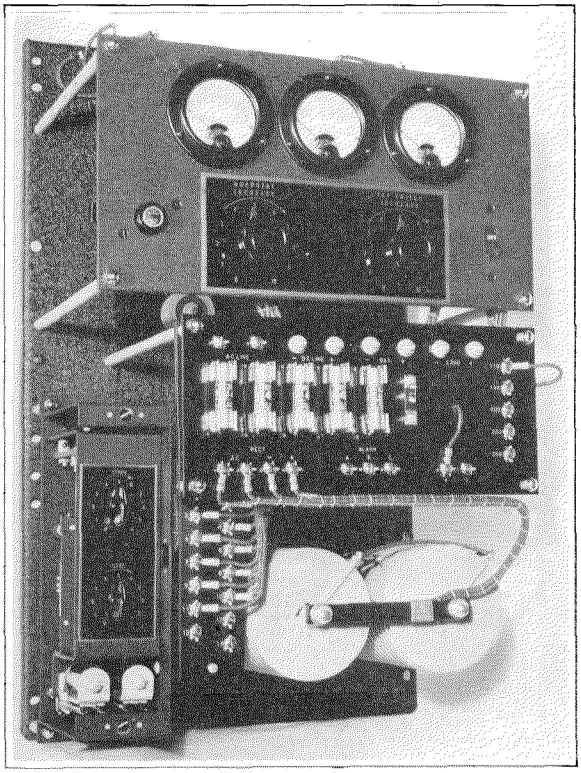

Fig. 12—Automatic Telephone Battery Charger Employing Relays.

as the current increases by suitable design and adjustment of the regulating reactors.

Selenium Rectifiers also have proved useful as automatic telephone battery chargers. A view of such a charger is shown in Fig. 12; Fig. 13 illustrates its electric circuit. An automatic battery charger of this type[3] is designed to maintain the battery potential between arbitrarily chosen values of 25 and 27 volts. As a rule batteries are continuously trickle charged and are given an occasional high rate charge. The normal or trickle charge rate is controlled by the rheostat *A*, manually adjusted to provide a charging current equal to the battery losses. The high rate charge, on the other hand, is controlled by the voltage relay *B*, the winding of which is connected in series with the rheostats *C* and *D*, permitting adjustment of the voltages at which the charge starts and stops. Normally the relay *B* is energized and its contacts are open but, when the battery voltage falls to 25 volts, the contact points close and short circuit the trickle charge rheostat *A* and fixed resistor *A'* through the operation of contactor *K*, thus increasing the rate of charge. At the same time the bi-metal strip begins to heat and in some two or three minutes closes the contact *E*, which in turn short circuits a portion of the relay control resistance, allowing the relay to pull up and open its contacts at 27 volts. By adjusting rheostats *C* and *D*, the battery terminal voltages can be maintained between any desired voltage limits.

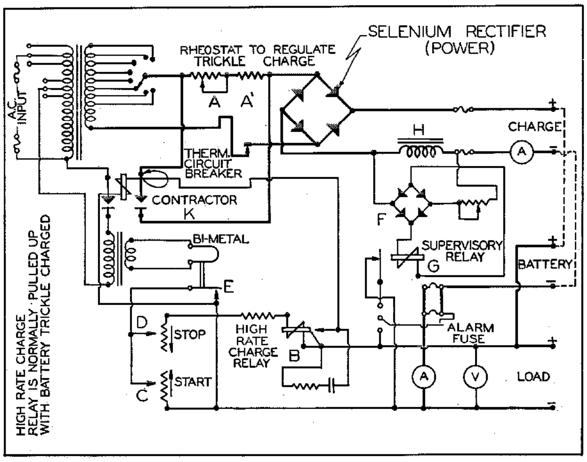
SELENIUM RECTIFIER (POWER)
RHEOSTAT TO REGULATE TRICKLE CHARGE
A
A'
A.C. INPUT
H
CHARGE
A
THERM. CIRCUIT BREAKER
CONTRACTOR K
F
BI-METAL
SUPERVISORY RELAY
G
BATTERY
E
D
STOP
HIGH RATE CHARGE RELAY
B
ALARM FUSE
START
C
A
V
LOAD
HIGH RATE CHARGE RELAY IS NORMALLY PULLED UP WITH BATTERY TRICKLE CHARGED

Fig. 13—Circuit of Automatic Battery Charger of Fig. 12.

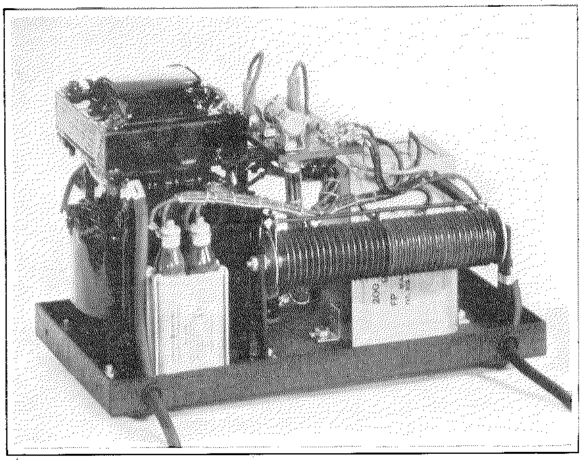

Fig. 14—Telegraph Battery Eliminator Supplying Both Line and Local Battery Current.

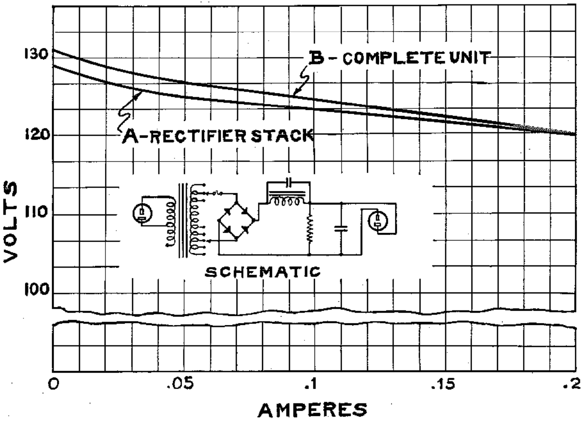

Fig. 15—Performance Characteristics and Circuit of Telegraph Battery Eliminator Shown in Fig. 14.

An interesting innovation in this automatic charger is the use of a small auxiliary bridge-connected Selenium Rectifier *F* operating the relay *G* to sound an alarm or give a visual indication in case of trouble. The reactor *H*, in series with the charging circuit, provides double frequency alternating current potential which is converted into d.c. by means of rectifier *F* energizing the relay *G*. The cessation of charging due to the line failure or any other cause results in operation of the alarm circuit. The filter reactor *H* also serves the purpose of reducing the a.c. component at the battery terminals to less than 40 millivolts.

To illustrate the inherent output voltage regulation of Selenium Rectifiers reference may be made to the telegraph battery eliminator (Figs. 14 and 15). The characteristic *A* shows the inherent voltage regulation of the selenium stack connected in the bridge circuit, each arm containing nine 1⅜″ diameter plates in series. This rectifier uses neither saturable reactors nor relays, static and dynamic regulation being accomplished by means of a tuned filter circuit. A high capacity electrolytic condenser is connected across the output terminals. The combination of this condenser with the tuned filter reactor reduces the a.c. component to a quarter of one percent of the d.c. voltage. The no-load output voltage is minimized by the bleeder resistor across the output terminals and a choke-input filter circuit.

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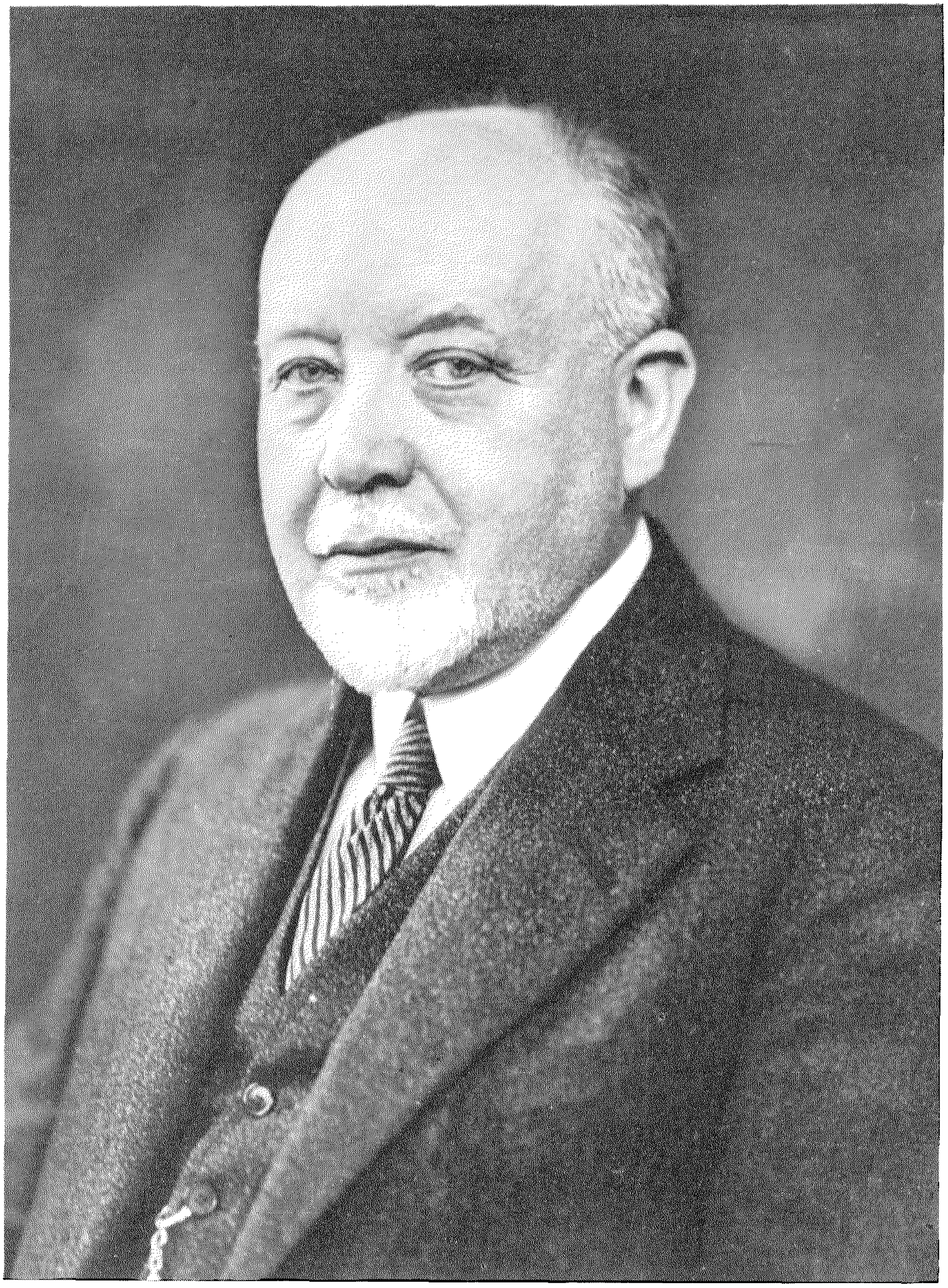
[3] U. S. Patent No. 2,229,432.



Peder Oluf Pedersen

Peder Oluf Pedersen*

1874-1941

The West Jutland shepherd boy who wrote to His King, who helped him to become a man of science.

> *As one of P. O. Pedersen's best friends through half a century, it is with the deepest grief that I learn today (August 30, 1941) that my friend has passed away.*
>
> *Danish engineering and technique has lost its first man.*
>
> *In the electro-technical field, in which he was my faithful collaborator during many happy years, he was a greatly esteemed research investigator. These years are a very dear remembrance to me.*
>
> *His enormous ability in covering a wide range and his great initiative, benefiting technical science in our country, carried him in late years into new working fields, but the friendship from our youth was continued down through all the years.*
>
> *I keep the remembrance of him in deep gratitude.*
>
> DR. VALDEMAR POULSEN.

IN the little volume, "Remembrances of my Childhood," published some years ago, Professor P. O. Pedersen gently and impressively tells how he started his career as one of our most esteemed scientists.

He was born 67 years ago in a modest farm house in the Varde region. His father had a little farm on the heath at Sig. Peder Oluf was an only son amongst many children. He was small for his age, slender in appearance and of delicate health. Seventeen of his ancestors had been Jutland farmers but, while he was still quite young, his parents began to fear that the boy would disappoint their expectation of carrying on the family tradition by some day taking over the heath farm at Sig.

Peder Oluf was reared in the same way as other young people of his region, and one can understand that it was an upbringing which marked all his subsequent development. He never owned bought toys and he never missed them. "There were stones in the fields," he said in his memoirs, "and they could be used in many ways, you know. There were the elder bushes whose branches could be fashioned into lovely flutes and pop-guns. When a little older one might also beg some nails and bits of wood from father for building small wind and water mills. There was always enough to busy oneself with. I never remember having felt bored as a child, and besides, not later on in my life either."

Practical Wisdom of Life from the Home and the Field

His father and mother were both religious, and the children were brought up in a Christianity where admonitions were taken not only from Luther's Catechism, but just as often from the wisdom of life derived from the many adages ("Sejh'er," i.e., sayings), continually used both earnestly and humorously. P. O. Pedersen mentions one which expresses something deeply rooted in the minds of many West Jutlanders and which has surely been of importance in his later research work, "De maa A et sejh, for A veed et" (I must not say that because I don't know it).

P. O. Pedersen evidently was reared in one of the excellent farming homes from whence various men of genius have come—men who, through their lifework, have played their part in creating the reputation of our country. Peder was a little late in starting school. He had a speech impediment and was unable to pronounce *G* and *K*. His mother, however, taught him how to say the difficult letters correctly by letting the boy follow with his fingers the movements of her tongue as she articulated *G* or *K*. He overcame his handicap and was an apt pupil at school.

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* This article appeared August 31, 1941 in *Berlingske Tidende* and is reprinted in translated form as a tribute to one of the world's outstanding Pioneers of Electrical Communication. *Berlingske Tidende* is one of Copenhagen's leading daily newspapers; its predecessor was the *Københavnske Danske Post-Tidende* which was taken over by E. H. Berling in or about the year 1748.

Arithmetic was his favorite subject and, by the time he was fourteen years old, the boy had learned so much that his teacher did not consider himself able to instruct him further in this field, but procured for him Poul la Cour's "Historical Mathematics," leaving the boy to study it by himself. It was a magnificent companion when he was out tending the farm's cattle during the summer. There were also other books which caught his interest, such as Hannover's "Theory of Movement." He was, nevertheless, a careful and conscientious herdsman. The working day often lasted twelve hours—and in later years the Professor often dreamed that he had forgotten for a day or two to move the sheep.

The Letter to His Majesty King Christian IX

Then came the great change in the little farmer boy's existence. He became more and more absorbed by technical problems. He always tried to solve them himself even if mastery of his books proved ever so difficult. But it was one of the doctrines he had absorbed in his childhood home: "By asking others one misses the joy and satisfaction of finding out oneself, and one never understands so well when relying upon someone else's explanation as when one has solved a problem for oneself."

The soil of the southern field of the farm was very poor, and the "Kapelbakke," especially, was so sandy that both the grass and the corn suffered much from early summer droughts. It was depressing to look at. And then it was that Peder Oluf, while he was lying in the field tending his cattle, hit upon a "perpetuum mobile" by which the necessary water could be pumped over the southern field. But here, for once, he met a problem so great and difficult that he could not solve it himself. He speculated upon this matter in the field until, suddenly, it was clear to him: he naturally ought to appeal to The King, Christian IX. His Majesty was the head of the country and would best be able to decide upon the right course.

It was then that Peder Oluf wrote the touching, simple-hearted letter to the King of the country. He ended the letter by saying: "God bless Your Majesty and highly esteemed family." The King passed the letter to Professor Julius Thomsen, the Rector of the Polytechnic Academy. When the boy immediately thereafter submitted a sketch illustrating a machine, the King himself granted P. O. Pedersen 300 Kroner annually and, in addition, the Ministry of Education provided a similar subsidy. Peder Oluf also gained free admission to Galster and Holboll's Course and was admitted to the home of a lecturer, S. C. Borch. The way thus was opened up towards the honourable scientific path now terminated.

The Meeting with Valdemar Poulsen

When P. O. Pedersen had been graduated from the Polytechnic Academy it was, quite naturally, his childhood recollections of West Jutland that became the determining factor in the career on which he embarked. The thirsty fields of his native abode and the inundations at Varde Creek seemed to him far more lovely than the Rhine and the other great European rivers he viewed later in life. He started as an hydraulic engineer and obtained, together with a friend, a prize for new harbor works at Oslo (Christiania). But it then happened that he met Valdemar Poulsen at the Borch home. P. O. Pedersen was engaged to be married to Borch's sister-in-law, and this young lady was a friend of Valdemar Poulsen's wife. The two young men quickly became sympathetic and commenced a collaboration which continued for many years and greatly influenced P. O. Pedersen's lifework.

Valdemar Poulsen was occupied with the utilisation of his invention of the telagraphone, and the collaboration between the two men became closer and more intense when Valdemar Poulsen, about 1903–04, had progressed to the point of building the Poulsen arc-generator for procuring continuous oscillations—the invention which became so decisively important in the later phenomenal development of the radio art. P. O. Pedersen assisted his friend in the solution of the great problems presented. The two engineers supplemented each other exceptionally well, and Pedersen rather quickly turned from his original engineering interests; he commenced to devote himself wholly to electro-physics, electro-technics, etc. P. O. Pedersen continued his explorations of the arc-generator until 1920, and he was successful in proving that a theory originating from Gottingen on the manner of operation of the arc-generator was wrong.

His Professorship—the First of its Kind in the World

Denmark's Polytechnic Academy was the first anywhere to include electrical communication technique as an obligatory examination subject. Upon application from Director Hagemann, P. O. Pedersen accepted the post as lecturer in this subject, despite the fact that it was new to him. He himself had to arrange all the material of instruction. Here was one of the many occasions in his life when he felt the inspiration of managing the thing himself, and where the learning from the heath at Sig could be applied. In 1912 P. O. Pedersen was appointed Professor.

It would be difficult for a layman to expound the many and varied scientific contributions which made P. O. Pedersen's name famous internationally. One of his biographers, Dr. Povl Vinding, cites P. O. Pedersen's investigations of the electric arc and publication in 1927 of his great work, "Propagation of Radio Waves," in which, aided by his great mathematical and technical knowledge combined with insight into the science of meteorology, he made clear the apparently enigmatical properties of short radio waves. Here we are in a domain of daily life interest to everybody. "This book," Dr. Vinding states, "is now a classic and is known to every radio engineer in the world."

The Leader and Rejuvenator of our Polytechnic Academy

When in 1922 Hannover retired as Director of the Polytechnic Academy, P. O. Pedersen was appointed his successor. Since then he was re-elected at the expiration of each five-year period for which the appointment is in force. In July, 1941, he was again re-elected. Despite the fact that P. O. Pedersen was then 67 years old and would exceed the age limit requirement prior to the expiration of his period as Rector (as the office is now called), the Teachers' Council, nevertheless, desired his re-election. By Royal Resolution his appointment was renewed until January 31st, 1947.

As Director and, subsequently, Rector of the Polytechnic Academy, Professor, Dr. Phil. P. O. Pedersen made an outstanding record and proved himself an eminent administrator. The development of youth always was one of his prime interests. Not least, of course, was he concerned with future engineers.

The great expansion of the Polytechnic Academy on the former military site at Østervoldgade was achieved under P. O. Pedersen's leadership and in accordance with his proposals.

The Man and the Evaluation of His Work

P. O. Pedersen was not only a scientist, but also, in marked degree, a realist. He was hearty in nature and possessed a fine mind. He was greatly interested in collaboration amongst scientists throughout the world and was seriously troubled when conditions impeded such collaboration. He thoroughly appreciated the importance of technique in progress. Hence he asserted so ardently that we were not only to keep our technical instruction on a level with that of other countries, but to surpass them where possible. He took the initiative some years ago in founding the Academy for Technical Sciences, of which he was President at the time of his death.

Many marks of honor were conferred on Professor P. O. Pedersen. He was Kommandør af 1 Grad (Commander of 1st Order) and Dannebrogsmand. In 1913 he received the Medal for Merit in Gold for his work with Dr. Valdemar Poulsen in connection with wireless telegraphy. He held the Ørsted Medal and the Gold Medal from the American Institute of Radio Engineers. But he said about himself: "My task has been the modest one of studying and developing what others have initiated." Gentle and reserved in appearance, his was a personality that impelled respect. He was able to obtain results without applying strong measures.

Telephone and Telegraph Statistics of the World

Compiled by Chief Statistician's Division, American Telephone and Telegraph Company

Telephone Development of the World, by Countries
January 1, 1940

COUNTRIES	NUMBER OF TELEPHONES			Per Cent of Total World	Telephones Per 100 Population
	Government Systems	Private Companies	Total		
NORTH AMERICA:					
United States	—	20,830,950	20,830,950	48.85%	15.85
Canada	212,619	1,184,653	1,397,272	3.28%	12.35
Central America	13,799	18,881	32,680	.08%	0.39
Mexico	1,337	174,263	175,600	.41%	0.88
West Indies—					
Cuba	610	56,462	57,072	.13%	1.33
Puerto Rico	531	16,227	16,758	.04%	0.90
Other Places in the West Indies	9,785	19,502	29,287	.07%	0.36
Other Places in North America	—	19,108	19,108	.04%	4.87
Total	238,681	22,320,046	22,558,727	52.90%	12.16
SOUTH AMERICA:					
Argentina	—	434,017	434,017	1.02%	3.30
Bolivia	—	2,611	2,611	.006%	0.08
Brazil	1,291	271,437	272,728	.64%	0.62
Chile	—	84,151	84,151	.20%	1.80
Colombia	8,900	32,787	41,687	.10%	0.47
Ecuador	4,600	3,050	7,650	.02%	0.27
Paraguay	—	3,658	3,658	.01%	0.38
Peru	—	32,286	32,286	.07%	0.48
Uruguay†	34,810	11,846	46,656	.11%	2.20
Venezuela	740	27,910	28,650	.07%	0.80
Other Places in South America†	3,018	—	3,018	.007%	0.54
Total	53,359	903,753	957,112	2.25%	1.05
EUROPE:					
Belgium	430,000	—	430,000	1.01%	5.12
Bulgaria	31,225	—	31,225	.07%	0.48
Denmark	17,813	441,944	459,757	1.08%	11.95
Eire#	45,513	—	45,513	.11%	1.54
Finland†	7,720	177,736	185,456	.43%	4.79
France†	1,589,595	—	1,589,595	3.73%	3.79
Germany*	4,226,504	—	4,226,504	9.91%	5.28
Great Britain and No. Ireland#	3,375,902	—	3,375,902	7.92%	7.06
Greece	5,967	48,437	54,404	.13%	0.76
Hungary	178,325	790	179,115	.42%	1.76
Italy*	—	650,000	650,000	1.52%	1.49
Latvia##	83,650	—	83,650	.20%	4.20
Lithuania†	26,591	—	26,591	.06%	1.03
Netherlands	460,000	—	460,000	1.08%	5.22
Norway*	153,000	97,000	250,000	.59%	8.52
Portugal	20,366	52,506	72,872	.17%	0.94
Roumania	—	102,268	102,268	.24%	0.51
Russia¶	1,272,500	—	1,272,500	2.98%	0.75
Spain	—	300,000	300,000	.70%	1.18
Sweden	863,102	1,697	864,799	2.03%	13.64
Switzerland	462,013	—	462,013	1.08%	10.99
Yugoslavia	72,000	—	72,000	.17%	0.45
Other Places in Europe	437,253	134,577	571,830	1.34%	1.11
Total	13,759,039	2,006,955	15,765,994	36.97%	2.74
ASIA:					
British India##	31,878	51,500	83,378	.20%	0.02
China	45,000	115,000	160,000	.37%	0.04
Japan##	1,367,958	—	1,367,958	3.21%	1.89
Other Places in Asia	211,129	99,034	310,163	.73%	0.15
Total	1,655,965	265,534	1,921,499	4.51%	0.18
AFRICA:					
Egypt	67,983	—	67,983	.16%	0.30
Union of South Africa#	220,288	—	220,288	.52%	2.13
Other Places in Africa	140,968	1,460	142,428	.33%	0.11
Total	429,239	1,460	430,699	1.01%	0.27
OCEANIA:					
Australia*	661,996	—	661,996	1.55%	9.51
Hawaii	—	37,154	37,154	.09%	8.78
Netherlands Indies	48,321	4,492	52,813	.12%	0.08
New Zealand#	217,869	—	217,869	.51%	13.28
Philippine Islands	2,410	30,386	32,796	.08%	0.20
Other Places in Oceania	5,213	380	5,593	.01%	0.25
Total	935,809	72,412	1,008,221	2.36%	1.03
TOTAL WORLD	17,072,092	25,570,160	42,642,252§	100.00%	1.97

† January 1, 1939. ## March 31, 1939. * June 30, 1939. # March 31, 1940.

¶ U.S.S.R., including Siberia and Associated Republics, January 1, 1939.

§ Approximately 56% of this total are automatic or "dial" telephones, including 10,351,000 "dial" telephones in the United States.

Telephone and Telegraph Wire of the World, by Countries

January 1, 1940

Countries	Service Operated By (See Note)	Miles of Telephone Wire			Miles of Telegraph Wire		
		Number of Miles	Per Cent of Total World	Per 100 Population	Number of Miles	Per Cent of Total World	Per 100 Population
NORTH AMERICA:							
United States	P.	95,150,000	53.12%	72.41	2,300,000	34.14%	1.75
Canada	P.G.	5,518,000	3.08%	48.77	367,000	5.45%	3.24
Central America	P.G.	62,000	.04%	0.75	23,000	.34%	0.28
Mexico	P.	688,000	.38%	3.47	100,000	1.49%	0.50
West Indies:							
Cuba	P.	283,000	.16%	6.60	11,000	.16%	0.26
Puerto Rico	P.	39,000	.02%	2.10	2,000	.03%	0.11
Other Places in West Indies	P.G.	116,000	.07%	1.44	8,000	.12%	0.10
Other Places in North America	P.	25,000	.01%	6.38	11,000	.16%	2.81
Total		101,881,000	56.88%	54.92	2,822,000	41.89%	1.52
SOUTH AMERICA:							
Argentina	P.	1,738,000	.97%	13.21	165,000	2.45%	1.25
Bolivia	P.	5,500	.003%	0.17	5,000	.07%	0.16
Brazil	P.	1,208,000	.68%	2.74	113,000	1.68%	0.26
Chile	P.	330,000	.18%	7.06	30,000	.45%	0.64
Colombia	P.G.	162,000	.09%	1.83	22,000	.33%	0.25
Ecuador	P.G.	10,000	.006%	0.35	5,000	.07%	0.17
Paraguay	P.	8,500	.005%	0.88	3,500	.05%	0.36
Peru	P.	133,000	.07%	2.00	13,000	.19%	0.20
Uruguay†	P.G.	160,000	.09%	7.54	8,000	.12%	0.38
Venezuela	P.	113,000	.06%	3.17	8,000	.12%	0.23
Other Places in South America	G.	6,000	.003%	1.08	500	.01%	0.09
Total		3,874,000	2.16%	4.27	373,000	5.54%	0.41
EUROPE:							
Belgium†	G.	2,000,000	1.12%	23.85	35,000	.52%	0.42
Bulgaria	G.	90,000	.05%	1.39	5,000	.07%	0.08
Denmark	P.	1,557,000	.87%	40.46	6,500	.10%	0.17
Eire#	G.	149,000	.08%	5.04	22,000	.33%	0.74
Finland†	P.	324,000	.18%	8.37	23,000	.34%	0.59
France†	G.	6,018,000	3.36%	14.35	317,000	4.70%	0.76
Germany##	G.	18,045,000	10.07%	22.63	237,000	3.52%	0.30
Great Britain and No. Ireland#	G.	16,300,000	9.10%	34.10	240,000	3.56%	0.50
Greece	P.G.	188,000	.11%	2.64	38,000	.56%	0.53
Hungary†	G.	468,000	.26%	4.63	53,000	.79%	0.52
Italy†	P.	1,736,000	.97%	4.01	278,000	4.13%	0.64
Latvia##	G.	327,000	.18%	16.43	4,500	.07%	0.23
Lithuania†	G.	82,000	.05%	3.18	2,500	.04%	0.10
Netherlands†	G.	1,385,000	.77%	15.87	9,000	.13%	0.10
Norway**	P.G.	738,000	.41%	25.19	22,000	.33%	0.75
Portugal	P.G.	199,000	.11%	2.58	18,000	.27%	0.23
Roumania	P.	431,000	.24%	2.15	48,000	.71%	0.24
Russia¶	G.	2,000,000	1.12%	1.17	600,000	8.90%	0.35
Spain	P.	1,500,000	.84%	5.91	90,000	1.33%	0.35
Sweden	G.	3,358,000	1.87%	52.96	14,000	.21%	0.22
Switzerland	G.	1,630,000	.91%	38.76	13,000	.19%	0.31
Yugoslavia†	G.	153,000	.09%	0.98	57,000	.85%	0.36
Other Places in Europe	P.G.	1,933,000	1.08%	3.74	112,000	1.66%	0.22
Total		60,611,000	33.84%	10.55	2,244,500	33.31%	0.39
ASIA:							
British India ##	P.G.	460,000	.26%	0.13	366,000	5.43%	0.10
China	P.G.	600,000	.33%	0.14	100,000	1.48%	0.02
Japan##	G.	4,864,000	2.72%	6.73	233,000	3.46%	0.32
Other Places in Asia	P.G.	976,000	.54%	0.48	233,000	3.46%	0.11
Total		6,900,000	3.85%	0.65	932,000	13.83%	0.09
AFRICA:							
Egypt	G.	397,000	.25%	1.77	26,000	.39%	0.12
Union of South Africa#	G.	937,000	.52%	9.06	30,000	.45%	0.29
Other Places in Africa	G.	437,000	.22%	0.34	150,000	2.22%	0.12
Total		1,771,000	.99%	1.10	206,000	3.06%	0.13
OCEANIA:							
Australia*	G.	2,918,000	1.63%	41.92	108,000	1.60%	1.55
Hawaii	P.	125,000	.07%	29.55	0	.00%	0.00
Netherlands Indies	G.	262,000	.15%	0.37	20,000	.29%	0.03
New Zealand#	G.	670,000	.37%	40.83	18,000	.27%	1.10
Philippine Islands	P.	81,000	.05%	0.50	10,000	.15%	0.06
Other Places in Oceania	G.	17,000	.01%	0.75	4,000	.06%	0.18
Total		4,073,000	2.28%	4.14	160,000	2.37%	0.16
TOTAL WORLD		179,110,000	100.00%	8.27	6,737,500	100.00%	0.31

NOTE: Telegraph service is operated by Governments, except in the United States and Canada. In connection with telephone wire, P. indicates that the telephone service is wholly or predominantly operated by private companies. G. wholly or predominantly by the Government, and P.G. by both private companies and the Government. See preceding table.

* June 30, 1939. # March 31, 1940. ## March 31, 1939.

¶ U.S.S.R., including Siberia and Associated Republics, January 1, 1939. ** June 30, 1938. † January 1, 1939.

Telephone Development of Large Cities

January 1, 1940

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones Per 100 Population
ARGENTINA:			
Buenos Aires	3,400,000	268,956	7.91
AUSTRALIA:†			
Adelaide	321,000	35,935	11.19
Brisbane	326,000	35,805	10.98
Melbourne	1,036,000	135,518	13.08
Sydney	1,289,000	159,825	12.40
BELGIUM:††			
Antwerp	560,000	48,696	8.70
Brussels	991,000	127,639	12.88
Liege	433,000	29,885	6.90
BRAZIL:			
Rio de Janeiro	1,940,000	103,797	5.35
CANADA:			
Montreal	1,095,000	187,158	17.09
Ottawa	203,200	40,829	20.09
Toronto	807,900	214,782	26.59
Vancouver	292,000	77,362	26.49
CHILE:			
Santiago	860,000	44,487	5.17
CHINA:			
Hong Kong	850,000	22,606	2.66
Shanghai≠	3,750,000	79,554	2.12
CUBA:			
Havana	725,000	45,651	6.30
DENMARK:			
Copenhagen	900,000	220,202	24.47
EIRE:#			
Dublin	488,000	24,893	5.10
FINLAND:†			
Helsinki	305,000	51,328	16.83
FRANCE:†			
Bordeaux	260,000	23,311	8.97
Lille	200,000	18,566	9.28
Lyon	650,000	39,369	6.06
Marseille	915,000	38,801	4.24
Paris	2,830,000	437,139	15.45
GERMANY:##			
Berlin	4,339,000	599,911	13.83
Breslau	623,000	48,203	7.74
Cologne	771,000	75,393	9.78
Dresden	821,000	75,569	9.21
Dortmund	585,000	28,945	4.95
Essen	672,000	36,743	5.47
Frankfort-on-Main	647,000	68,112	10.52
Hamburg-Altona	1,724,000	188,861	10.96
Leipzig	767,000	73,959	9.64
Munich	866,000	97,215	11.23
Vienna	1,874,000	180,165	9.61
GREAT BRITAIN AND NO. IRELAND:##			
Belfast	415,000	23,336	5.62
Birmingham	1,259,000	79,847	6.34
Bristol	450,000	31,376	6.97
Edinburgh	465,000	47,066	10.12
Glasgow	1,150,000	72,359	6.29
Hull#	361,000	25,354	7.02
Leeds	568,000	36,825	6.48
Liverpool	1,265,000	79,228	6.26
London—(City and County of London)	4,028,000	717,468	17.81
Manchester	1,015,000	68,191	6.72
Newcastle	482,000	28,167	5.84
Sheffield	522,000	28,776	5.51
HAWAII:			
Honolulu	179,000	25,408	14.19
HUNGARY:†			
Budapest	1,635,000	107,906	6.60
Szeged	141,000	2,635	1.87
ITALY:†			
Bologna	315,000	14,738	4.68
Milan	1,206,000	109,168	9.05
Naples	920,000	31,373	3.41
Rome	1,280,000	122,442	9.57
Venice	284,000	10,209	3.59
JAPAN:##			
Kobe	989,000	46,265	4.68
Kyoto	1,160,000	51,457	4.44
Nagoya	1,224,000	46,122	3.77
Osaka	3,321,000	176,697	5.32
Tokio	6,458,000	290,510	4.50
LATVIA:##			
Riga	391,000	31,795	8.13
LITHUANIA:†			
Kaunas	110,000	10,124	9.20
MEXICO:			
Mexico City	1,450,000	95,673	6.60
NETHERLANDS:†			
Amsterdam	794,000	67,927	8.56
Haarlem	174,000	14,474	8.32
Rotterdam	635,000	44,145	6.95
The Hague	540,000	57,635	10.67
NEW ZEALAND:			
Auckland	215,000	33,012	15.35
Wellington	160,000	32,083	20.05
NORWAY:*			
Oslo	417,000	73,786	17.69
PHILIPPINE ISLANDS:			
Manila	770,000	25,715	3.34
PORTUGAL:			
Lisbon	710,000	33,902	4.78
ROUMANIA:			
Bucharest	910,000	50,347	5.53
SWEDEN:			
Göteborg	281,000	63,585	22.63
Malmö	155,000	29,862	19.27
Stockholm	460,000	184,722	40.16
SWITZERLAND:			
Basel	165,000	38,916	23.59
Bern	125,000	31,662	25.33
Geneva	125,000	30,950	24.76
Zurich	320,000	73,914	23.10
URUGUAY:†			
Montevideo	705,000	33,447	4.74
UNITED STATES: (See Note)			
New York	7,442,000	1,669,904	22.44
Chicago	3,390,000	997,174	29.42
Los Angeles	1,444,000	456,564	31.62
Cleveland	1,153,900	264,560	22.93
Total 6 Exchange Areas with over 1,000,000 Population	17,245,900	4,191,428	24.30
Milwaukee	748,700	162,758	21.74
San Francisco	648,800	290,990	44.85
Washington	654,000	254,042	38.84
Minneapolis	541,000	155,362	28.72
Total 13 Exchange Areas with 500,000 to 1,000,000 Population	8,922,900	2,265,558	25.39
Seattle	422,000	128,613	30.48
Denver	321,500	108,244	33.67
Omaha	246,600	68,452	27.76
Hartford	242,700	67,685	27.89
Total 30 Exchange Areas with 200,000 to 500,000 Population	9,503,500	2,210,282	23.26
Total 49 Exchange Areas with over 200,000 Population	35,672,300	8,667,268	24.30

NOTE: There are shown, for purposes of comparison with cities in other countries, the total development of all cities in the United States in certain population groups, and the development of certain representative cities within each of such groups.

* June 30, 1939. ## March 31, 1939. # March 31, 1940.

≠ International Settlement and French Concession. †† February 28, 1938. † January 1, 1939.

Telephone Conversations and Telegrams

YEAR 1939

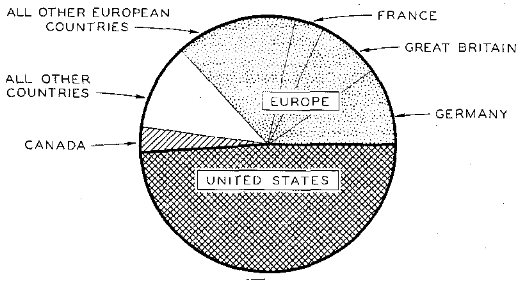
COUNTRY	Number of Telephone Conversations	Number of Telegrams	Total Number of Wire Communications	PER CENT OF TOTAL WIRE COMMUNICATIONS Telephone Conversations	Telegrams	WIRE COMMUNICATIONS PER CAPITA Telephone Conversations	Telegrams	Total
Australia	637,000,000	17,998,000	654,998,000	97.3	2.7	91.9	2.6	94.5
Belgium†	320,000,000	5,900,000	325,900,000	98.2	1.8	38.5	0.7	39.2
Canada	2,774,000,000	11,629,000	2,785,629,000	99.6	0.4	246.3	1.0	247.3
Denmark	726,000,000	1,748,000	727,748,000	99.8	0.2	189.5	0.5	190.0
Finland†	309,000,000	811,000	309,811,000	99.7	0.3	80.3	0.2	80.5
France†	972,000,000	27,524,000	999,524,000	97.2	2.8	23.2	0.6	23.8
Germany†	3,640,000,000	21,701,000	3,661,701,000	99.4	0.6	45.8	0.3	46.1
Gt. Britain and Northern Ireland	2,255,000,000	59,484,000	2,314,484,000	97.4	2.6	47.4	1.3	48.7
Hungary†	187,000,000	2,439,000	189,439,000	98.7	1.3	19.5	0.3	19.8
Japan†	5,339,000,000	68,475,000	5,407,475,000	98.7	1.3	74.2	0.9	75.1
Netherlands†	468,000,000	3,588,000	471,588,000	99.2	0.8	53.9	0.4	54.3
Norway†	281,000,000	3,489,000	284,489,000	98.8	1.2	96.1	1.2	97.3
Sweden	1,195,000,000	4,641,000	1,199,641,000	99.6	0.4	189.0	0.7	189.7
Switzerland	335,000,000	2,039,000	337,039,000	99.4	0.6	79.8	0.5	80.3
Union of South Africa	317,000,000	6,863,000	323,863,000	97.9	2.1	30.9	0.7	31.6
United States	30,300,000,000	195,000,000	30,495,000,000	99.4	0.6	231.5	1.5	233.0

NOTE: Telephone conversations represent completed local and toll or long distance messages. Telegrams include inland and outgoing international messages.

† Year 1938.

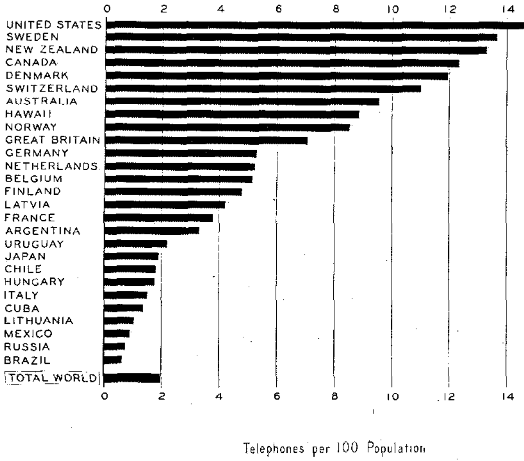
DISTRIBUTION OF THE WORLD'S TELEPHONES

January 1, 1940



TELEPHONES PER 100 POPULATION

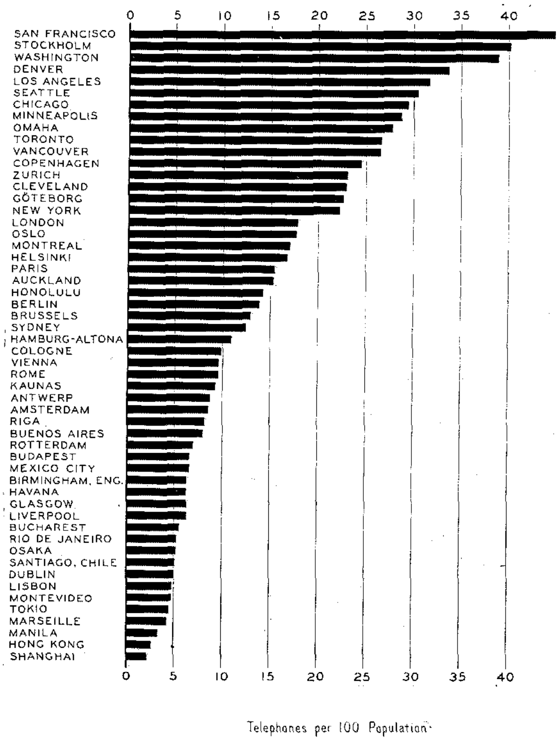
January 1, 1940



TELEPHONES PER 100 POPULATION

OF LARGE CITIES

January 1, 1940



Recent Telecommunications Developments

Columbia Broadcasting System's New 50 kw Broadcasting Station WABC.—With a special inaugural program, the new broadcaster was placed in service October 18, 1941. The station is uniquely located on a built-up island in Long Island Sound just off New Rochelle, New York, to provide optimum coverage of Metropolitan New York. The equipment was designed and constructed to CBS specifications by the Federal Telegraph unit of the International Telephone & Radio Manufacturing Corporation.

The main transmitter provides for 50 kw output with an auxiliary 5 kw transmitter arranged for automatic cutover in case of failure of the main equipment. Performance of these equipments represents a new high in the broadcasting field.

• • •

ITG 200 Transmitter for Fixed Station Use.—This new International Telephone & Radio Manufacturing Corporation transmitter has a nominal carrier power rating of 200 watts and is arranged for continuous frequency coverage from 2 to 20 mc (150 to 15 meters). Facilities are also included for four crystal frequencies. Frequency change is accomplished entirely from front panel controls. The specially designed electric oscillator provides excellent frequency stability for CW, MCW and telephone emission. The unit operates from a 220 volt, 50/60 cycle, single phase power source.

• • •

New Aircraft Transmitter.—The International Telephone & Radio Manufacturing Corporation is now manufacturing the ITA 100 transmitter, an electric oscillator type unit providing continuously variable frequency coverage from 2000 kc to 16,000 kc and 250 kc to 600 kc, with a carrier power output to the antenna of 100 watts on the high, and 50 watts on the low, frequency range.

The self-contained class-B high level modulator provides for telephonic and MCW operation in addition to CW. Two individual exciter units provide a frequency stability of .05% over the wide frequency range. A specially designed output circuit enables the transmitter to operate into a fixed or trailing wire antenna.

The transmitter is wholly self-contained in a shock mounted cabinet 12½″ high, 18″ long and 9½″ deep. High voltage is supplied by an external dynamotor unit operating from 24 volts d.c. Alternatively, the unit may be supplied to operate from 12 volts d.c.

• • •

Precision Wavemeter.—A portable, battery operated, absorption type wavemeter has been developed by the International Telephone & Radio Manufacturing Corporation to satisfy a definite demand in the field of frequency measurement. The instrument consists of a tuned circuit and a vacuum tube voltmeter-type of resonance indicator. Seven plug-in coils in bakelite cases are utilized to cover frequencies from 50 kc to 50 mc. Its accuracy of calibration at any frequency is better than 0.25%.

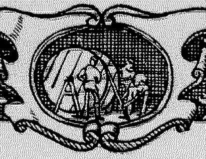
• • •

Australian Developments in Automatic Telephony.—Telephone development in the suburbs of capital cities is being met by the Australian Commonwealth Government in a novel manner. Small satellite exchanges of 600 to 900 lines capacity will be installed in buildings of the "double garage" type on sites subsequently to be occupied by more elaborate branch exchanges. Thus, immediate savings in line plant are achieved without heavy investment in buildings; and, when development justifies provision of the branch exchanges, the initial equipment can be utilized in its original location, or elsewhere, inasmuch as it is of standard construction.

Standard Telephones and Cables Pty. Limited has received an order for ten initial exchanges for installation in Sydney, Melbourne and Adelaide. The equipment will be the British Post Office 2000 type step-by-step system employing line finders and will be manufactured partly in London and partly in Sydney. The contract is the largest placed by the Commonwealth within the last five years for this type of equipment.

International
Standard Electric Corporation

Printed in U.S
4111



ELECTRICAL COMMUNICATION

Technical Journal of the
INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION
and Associate Companies

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1942

VOL. 20 No. 3

ELECTRICAL COMMUNICATION

Technical Journal of the
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H. T. KOHLHAAS, Editor

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Published Quarterly by the

International Standard Electric Corporation

67 BROAD STREET, NEW YORK, N.Y., U.S.A.

H. M. Pease, President S. G. Ordway, Secretary and Treasurer

Subscription, $3.00 per year; single copies, 75 cents

Volume XX 1942 Number 3

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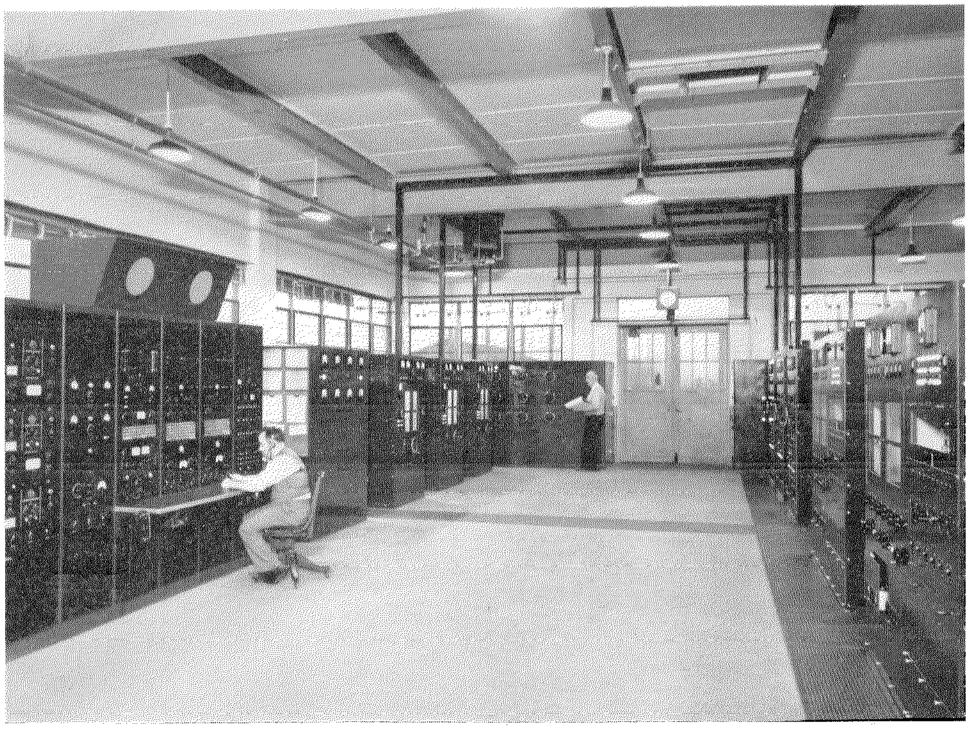

TRANSMITTER ROOM OF THE COLUMBIA BROADCASTING SYSTEM'S 50 KW SHORT WAVE INTERNATIONAL BROADCAST STATIONS WCRC AND WCBX INAUGURATED JANUARY 1, 1942. THE EQUIPMENT WAS DESIGNED AND BUILT BY THE FEDERAL TELEGRAPH COMPANY.

Milestones of Communication Progress

By H. T. KOHLHAAS, E. E., Member A. I. E. E.
Editor, Electrical Communication

In the twenty years that have elapsed since Electrical Communication first appeared, the art of electrical communication has made astonishing progress. Companies in the International Telephone and Telegraph Group throughout the world have contributed generously to this advance, embracing the fields of research, development and manufacture, as well as the development and operation of telephone, telegraph and radio systems—accomplishments which to a considerable degree have been recorded in the pages of this journal. It is felt, therefore, that this review giving the reader what may be regarded as a rather comprehensive perspective of communication developments of this twenty year period will be of interest.

In 1942, Electrical Communication will depart from its normal custom of publishing an international communications review of the previous year because of the impracticability of presenting a comprehensive report of communications activities in a world disturbed by war. In any case, it will be appreciated that many activities cannot at present be discussed.

Introduction

ELECTRICAL COMMUNICATION in 1942 completes its twentieth year of publication. Recorded in its pages are descriptions of developments and activities representing practically all phases of the communication art. It is pertinent, therefore, to examine briefly the picture formed by these publications, using the opportunity to place in their proper perspective some of the principal achievements recorded in the journal.

Taking first the task of planning and coordinating long distance telephone communication, an outstanding event is recorded in the creation in 1924 of the International Consultative Committee on long distance telephony in Europe. It followed a proposal made by Sir Frank Gill in his Presidential Address to the Institution of Electrical Engineers in 1922.[1, 2, 3, 4]

Achievements in long distance international radiotelephony took place in rapid sequence. Between 1923 and 1926 we find a succession of recorded steps leading to the establishment of the first transatlantic telephone circuit between the United States and England.[5, 6, 7] In 1930 we read about the first Madrid-Buenos Aires radiotelephone circuit, inaugurated in 1929, followed shortly by the first radiotelephone circuit between the Americas. [8 to 16 incl.] In 1931 we read of the first demonstrations of single sideband short wave radiotelephony carried out between Buenos Aires and Madrid and between Madrid and Paris, establishing the now well-recognized improvements in transmission efficiency and the economies which this method makes possible.[17]

In 1931[18] and the following years, a series of articles described outstanding developments in the ultra-high frequencies. Long distance telephone communication was established across the English Channel on approximately 1,600 megacycles using very sharp beams. Work in this general field was to be continued with great activity, and publications appeared on propagation of these very high frequencies in 1936 and 1937, the latter including a description of the first multi-channel ultra-short wave telephone link.[19 to 24 incl.] Later on, work on ultra-high frequencies was directed also to television transmission. On the one hand, we find references to the Eiffel Tower television station in 1939, delivering 30 kw to an exceptionally long feeder over the wide band of frequencies necessary for television;[25] on the other, to transmission over dielectric guides with experiments on frequencies from 1,000 mc to 30,000 mc, using various types of positive grid triodes, klystrons, magnetrons or other tube structures.[26 to 33 incl.]

High power broadcasting on intermediate frequencies and high frequencies takes a prominent place in these publications. We read in 1932 of the Prague Station with 120 kw carrier,[36] followed two years later by the Budapest Station with the same carrier power, and unique for its anti-fading mast antenna over 1,000 feet high, the highest antenna ever constructed.[37, 38]

On higher frequencies, mention was made of two British Empire broadcasters added in 1937 at Daventry, rated at 50 kw carrier power at 22 megacycles.[39]

Early long distance telephone communication to ships at sea is also recorded:[40, 41] on the Berengaria in 1929; the Belgenland in the winter of 1930–31 and the Empress of Britain in 1931–32. Remarkable results were obtained; for example, successful conversations were held with London when a ship was in the China Sea and with New York when at Alexandria. Service to the Majestic was opened on February 14, 1930, at first for incoming calls only.

References to important work done on automatic direction finders are found in several articles. An airplane automatic radio compass was described in 1936. This equipment was introduced in the United States in 1937, and important experiments were made and papers published on night error and mountain effects.[42, 43, 44]

The subject of ground direction finders avoiding polarization errors by the use of spaced vertical antennae with H.F. transmission line to distant receivers is also found in these pages, as is that of aerial navigation.[43, 45, 46, 47, 48]

Less spectacular, but fundamental, are developments in automatic telephony and transmission, fields which are represented in numerous issues of this journal. The general tendencies appear clearly from these articles. Notable is the application of machine switching to large areas, the rapid expansion of rural automatic networks and, in recent years, schemes involving complete national dialing in some of the smaller European countries, either on a timed and zoned metering basis or on an automatic ticketing basis.[49 to 61 incl.]

These national dialing schemes led to the development of a commercially practicable system for automatic toll ticketing, each ticket containing a complete record of each subscriber's telephone call. We find in 1937, 1939 and 1940 a series of articles showing how automatic toll ticketing was developed and introduced commercially.[62, 63, 64, 65]

The wire transmission systems went through an evolution just as remarkable as that of automatic switching. We find references to the first carrier telephone systems in Brazil and Australia in 1924 and 1925, respectively;[66, 67] the first loaded and repeatered long distance French telephone cable in 1927;[68] and the first twelve-channel carrier systems and the first coaxial cable in England in 1937.[69, 70]

Through these articles, prepared and published year after year, often when the value of new systems was not yet fully established or even appreciated, we can sense the enthusiastic and coordinated effort of an organization confronted with many problems, but with experience and personnel drawn from all parts of the world; an organization mainly under the general technical guidance and licensing of the International Standard Electric Corporation, which, in a period covering approximately twenty years, has created an extensive research and development organization and a manufacturing organization capable of producing the everchanging and increasingly exacting matériel for the electrical communication and its many related fields.

Several lines of development, continued with confidence year after year, are only now yielding their reward in connection with war efforts. This is especially true of much of the work done on aerial navigation, on direction finding and in the general field of ultra-high frequencies.

The Communication Art in 1922

An indication of the state of the art in 1922 may be gleaned through quotations from an article by the late J. L. McQuarrie.[71]

"It is indeed fascinating to speak by wire with friends and business associates located within the same community, but with what a feeling of amazement does one engage in a long distance conversation and wonder at the marvelous possibilities of the telephone . . . in the year 1915, conversation was carried on between New York and San Francisco, a distance of 3,400 miles. This was accomplished by means of wires strung on poles over the vast stretches of prairie and mountainous country which lie between the central and western sections of the United States."

* * *

"Cables had been used for comparatively short lines within city boundaries, but they were not suitable for long distance communications. Improvements in design permitting the use of cables over long distances are among the most noteworthy in the development of the telephone art. It is now possible to communicate through cables over distances as great as those bridged in the past by overhead wires; in fact, a cable is now being installed for long distance service between New York and Chicago, nearly 1,000 miles in length.

"The attenuation of voice currents through submarine cables is greater than in the case of land cables, but even this obstacle has been surmounted. Three such cables (the longest in the world) were laid between the United States and Cuba in 1921, thus providing a telephone link between the cities of these two countries. An interesting feature of the design is that although each cable contains but a single path for a telephone circuit, the telephone path also provides two superimposed duplexed telegraph circuits.

"With its field of application as yet undetermined, but possessing important commercial possibilities, considerable study has been given to the development of radiotelephony and in 1915 spoken words were successfully transmitted by radio from Washington to Paris and Honolulu, the Paris message being the first telephone communication to bridge the Atlantic Ocean. During the past year radiotelephony has been applied to the commercial system in the form of a radio toll circuit between the coast of California and Catalina Island, a distance of about 30 miles. . . .

"Another notable demonstration of the interconnection of land lines and radio stations occurred recently when telephone communication was established between subscribers' stations in the United States and a transatlantic steamship located 300 miles from shore.

"A most interesting exhibition of long distance communication occurred in 1921, when commercial conversation was carried on between Havana, Cuba and Catalina Island, in the Pacific Ocean, a total distance of 5,730 miles; the circuit comprised 5,600 miles of land lines, 100 miles of submarine cable and 30 miles of radio.

"Multiplex telephony has been the dream of inventors for years and it has finally been achieved. A system has been devised and placed in commercial service which provides five commercial telephone channels over one pair of wires, and through the application of the principles of this system to telegraphy, ten duplexed telegraph channels may be secured over a single circuit.

"A novel application of radiotelephony is the distribution of music and speech from central or 'broadcasting' stations in such a manner that homes equipped with comparatively simple and inexpensive apparatus may receive lectures, music, weather reports, market quotations and other useful information and entertainment.

"One of the most recent developments is that of the loud speaking telephone used with marked success in connection with public addressing, both in and out of doors. On one occasion an assembly of 125,000 people, in an area of six acres, was able to hear the speaker without difficulty. By association with the commercial telephone service, speech may be transmitted to assemblages at points far distant from that at which the address is being delivered. At the recent memorial services at the National Cemetery at Arlington, Virginia, the address of the President of the United States was distinctly heard by an audience of 100,000 people at Arlington, 30,000 at New York and 20,000 at San Francisco. Loud speaking telephones are also being used in connection with radio receiving sets, thereby materially increasing the popularity of the 'broadcasting' service.

"Automatic telephone equipments, so arranged that stations may call one another without the intervention of an operator, have been in use for some time, but they have not been suitable for service in the larger metropolitan areas. The intricate traffic problems of these localities required a new type of system, which has been perfected and is now being installed in the larger cities."

International Consultative Committee of Long Distance Telephony (C. C. I. F.)

In 1922 Frank Gill (now Sir Frank, K.C.M.G., O.B.E.) "was elected President of the Institution of Electrical Engineers of which he had been a member since 1891 and selected as the subject of his inaugural address Electrical Communications with particular reference to international telephony. He drew attention to the achievements of the American Telephone & Telegraph Company in long distance telephony and pointed out that if distances alone were considered, telephone conversations could be carried on to all parts of the Continent of Europe and beyond with equal facilities. Long distance telephony had been possible in the U. S. A. because there had been one planning and coordinating authority, whereas there were some 40 in Europe, all with different ideas. Unless the circuit had been planned throughout with the same electrical characteristics, reflection and other losses occurred wherever there were variations. He proposed three alternative plans for dealing with this situation, one of which provided for an international telephone organization with supervisory engineering powers. Early in 1923 the Department of Posts, Telegraphs & Telephones in France called an international meeting, of Government officials only, to consider these proposals and in 1924 the International Consultative Committee of Long Distance Telephony (C. C. I. F.) was formed, based on Mr. Gill's third proposal. To the efforts of this Committee we owe the success of long distance telephony in Europe, but the formation of the Committee is due to the vision of Mr. Gill." [1, 2, 3, 4, 159]

Transatlantic Radio Telephony

(*a*) 1923 TESTS

On Sunday, January 14, 1923, while seated in his office at the New Southgate plant of the International Western Electric Company (now the International Standard Electric Corporation), Frank Gill (now Sir Frank), then European Chief Engineer of the International Western Electric Company, together with Postal officials of the British Government, listened for two hours to H. B. Thayer, then President of the American Telephone and Telegraph Company, and others talking from Mr. Thayer's office on the 26th floor of 195 Broadway, New York. Among others, a message was received in New York from London reading:

"Loudspeaker now being used—good results—great enthusiasm. Your interview on loudspeaker came through fine."

These tests recorded a distinct advance in the art over the transatlantic tests of 1915. A 5,400 metre wave was used; the output delivered to the antenna was 100 kw (peak power of single sideband).[5]

(*b*) TRANSATLANTIC TRANSMISSION

The one-way 1923 transatlantic radio transmission tests, referred to above, were conducted during the relatively favorable winter months, and it was appreciated that inauguration of radiotelephone transatlantic service undertaken on a sound engineering basis would require an extensive study of transmission characteristics. The carrying on of the extensive measurement program involved was possible through the cooperation of the American Telephone and Telegraph Company, the Radio Corporation of America and its associated companies, as well as the International Western Electric Company* and the British Post Office.

A paper[6] in the nature of a report was presented before the I.R.E., May 6, 1925, giving an analysis of observations of long wave transmission across the Atlantic over a period of about two years. Important conclusions were drawn involving effects due to solar radiation, illuminated and darkened hemispheres, disturbances in the earth's magnetic field, etc. It was pointed out that, in general, static noise is lower at the higher frequencies.

(*c*) BRITISH GENERAL POST OFFICE RADIO STATION AT RUGBY

Interest engendered by the experiments in two-way transatlantic radiotelephony focused at the British end in the Rugby Station of the G. P. O. This station, notable for its size and many novel features was described in 1926.[7]

Essentially the equipment consisted of the single sideband input, the high power radio amplifier and the necessary system of controls and protective arrangements.

Typical measured values when working on one portion of the aerial only, viz., that having a capacity of 0.33 μF, are cited as of interest.

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* Predecessor of International Standard Electric Corporation.

Aerial Circuit Power—257–306 kw
d-c Input Power—355–434 kw
Filament Power—48 kw
Efficiency Excluding Filament—72%
Efficiency Including Filament—64%
Voltage on Antenna—165,000–180,000 volts.

(*d*) TRANSATLANTIC TELEPHONY BETWEEN THE INSTITUTION OF ELECTRICAL ENGINEERS, LONDON, AND THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, N. Y.[7a]

"On Thursday, February 16, 1928, a demonstration of transatlantic telephony was given between the Institution of Electrical Engineers, London, and the American Institute of Electrical Engineers, New York, in joint session. By preliminary agreement, arrangements were made for receiving and for sending telephonic messages from the Council Rooms of the respective institutions and, in the case of London, provision was made by the British Post Office whereby an audience consisting chiefly of electrical engineers could listen in their Lecture Theatre to the proceedings, by the aid of a loudspeaker."

* * *

"MR. ARCHIBALD PAGE (London): I regard it as a great honour to be asked to take the chair on this historic occasion; it is also a gracious compliment to our Institution, and in accepting, which I do gladly, I desire to thank you, Mr. President, and the Members of the American Institute of Electrical Engineers most heartily. I welcome all present at the meeting now in session, and venture to predict that the proceedings will prove exceedingly interesting and likely to live not only in our memories, but to be quoted by succeeding generations of electrical engineers, as marking an important milestone in the advancement of electrical science."

* * *

"GENERAL J. J. CARTY (New York): Whereas, On this sixteenth day of February, 1928, the members of the Institution of Electrical Engineers assembled in London, and the members of the American Institute of Electrical Engineers assembled in New York, have held, through the instrumentality of the transatlantic telephone, a joint meeting at which those in attendance in both cities were able to participate in the proceedings, and hear all that was said, although the two gatherings were separated by the Atlantic Ocean; and as this meeting, the first of its kind, has been rendered possible by engineering developments in the application of electricity to communication by telephone; therefore,

"Be it Resolved, That this meeting wishes to express its feelings of deep satisfaction that, by the electrical transmission of the spoken word, these two national societies have been brought together in this new form of international assembly, which should prove to be a powerful agency in the increase of good-will and understanding among the nations; and

"Be It Further Resolved, That a record of this epoch-making event be inscribed in the minutes of each society."

"THE CHAIRMAN (London): Sir Oliver Lodge, who needs no introduction, is sitting beside me, and I have asked him to second the motion

"SIR OLIVER LODGE (London): It is surely right and fitting that a record of the transmission of human speech across the Atlantic be placed upon the minutes of those societies whose members have been instrumental in making such an achievement possible, and I second the proposal that has just been made from America.

"All those who in any degree have contributed to such a result—from Maxwell and Hertz downwards, including all past members of the old British Society of Telegraph Engineers—will rejoice at this further development of the power of long distance communication. Many causes have contributed to make it possible. That speech is transmissible at all, is due to the invention of the telephone. That speech can be transmitted by ether waves is due to the invention of the valve, and the harnessing of electrons for that purpose. That ether waves are constrained by the atmosphere to follow the curvature of the earth's surface is an unexpected bonus on the part of Providence, such as is sometimes vouchsafed in furtherance of human effort. The actual achievement of today at which we rejoice, and which posterity will utilise, must be accredited to the enthusiastic cooperation, and to the scientific and engineering skill of many workers in the background, whose names are not familiar to the public, as well as to those who are well known.

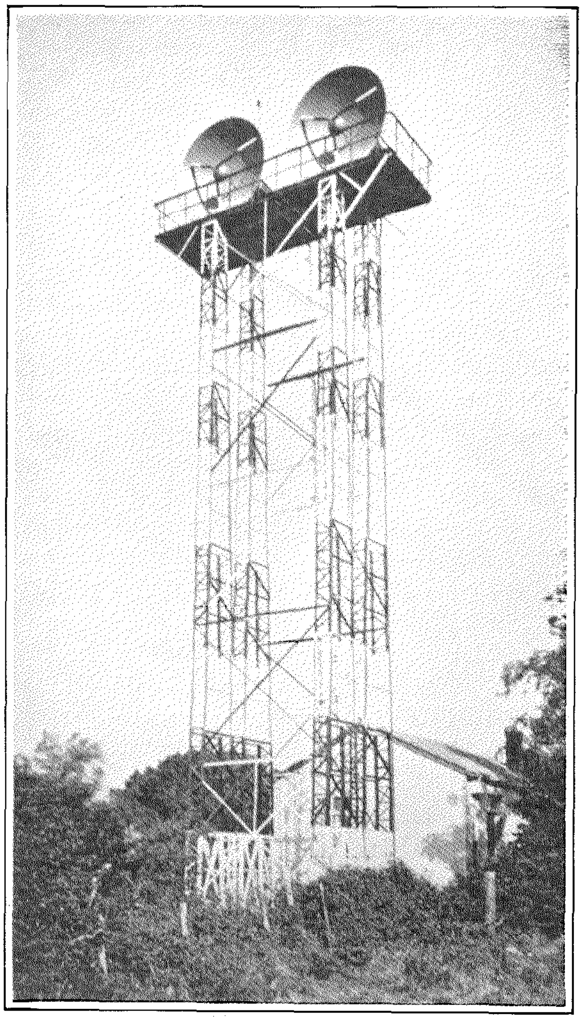
"The union and permanent friendliness of all branches of the English-speaking race, now let us hope more firmly established than ever, is an asset of incalculable value to the whole of humanity. Let no words of hostility be ever spoken."

"THE CHAIRMAN (London): Gentlemen, you have heard the Motion proposed by General Carty, and seconded by Sir Oliver Lodge. I now put it to the joint meeting. 'Those in favour.' 'Contrary.' 'Carried unanimously.'"

Short Wave Radiotelephone Links

(*a*) MADRID–BUENOS AIRES

Officially inaugurated in October, 1929, the Madrid–Buenos Aires radio link provided telephone subscribers with inter-continental and international facilities of the most modern type. The plans formulated by the International Telephone and Telegraph Corporation provided for connecting associate companies in South American telephone operating areas with the Spanish telephone network and, in addition, through Spain to other European networks.



Micro-Ray Towers (20 metres high).

Development was commenced at a time when knowledge of short wave telephony was meagre and the project required the solution of many special problems, including both the radio and low frequency portions of the equipment.[8 to 15 incl.]

The transmitting equipment designed by the International Telephone and Telegraph Laboratories, Inc., operated initially with a maximum of 12 kw peak power and the modulator circuits to permit 90 percent to 100 percent linear modulation.

(*b*) NEW YORK–BUENOS AIRES

The opening of radio facilities between New York and Buenos Aires, April 3, 1930, connecting 277,000 (now about 583,000) telephones in Argentina, Chile and Uruguay with 21,600,000 (now more than 25,000,000) telephones in the United States, Canada, Mexico and Cuba marked another important step in national and inter-continental telephonic communication.[16] Through the transatlantic radiotelephone service between New York and London, Buenos Aires and Madrid, and then New York and Buenos Aires, the telephone networks of three continents were placed in actual or potential contact with one another.

The New York–Buenos Aires link was the first two-way telephone circuit between the Americas. Like the other links just referred to, it is a true radiotelephone trunk line providing service to the entire telephone networks involved.

Subsequent to the opening of the Buenos Aires–New York link, companies in the I. T. T. group constructed radio stations in other South American countries providing telephone service to many countries and forming an extensive continental telephone network, serviceable also as point-to-point links in radio broadcasting.[72*]

(*c*) DISPLACED SIDEBAND ON SHORT WAVE LINKS

During early tests of radiotelephone circuits on wavelengths below 100 metres, fading in par-

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[*] See also article in this issue, "Operating Results on the New Buenos Aires–New York Twin Channel Single Sideband Short Wave Radiotelephone Link."

ticular was prominent. Research disclosed that it involved three separate aspects: diurnal variation, general fading and selective fading. These phenomena were discussed and analyzed mathematically in 1931[16a] with special reference to selective fading, it being assumed that sideband frequencies could be located sufficiently far from the carrier to be affected independently.

The study showed that improvement both in reliability and quality of transmission could be effected by the application of the displaced sideband method, and its use by I. T. & T. companies has proved distinctly advantageous. Examples are the Madrid-Buenos Aires and the Buenos Aires-Rio de Janeiro short wave radio links. In the latter, during heavy traffic periods, the displaced sideband system has been successfully combined with the usual type of transmission to give two commercial telephone channels. With good filters, this service is entirely satisfactory and gives added secrecy to the circuits.

Micro-Ray Radio

(a) DUPLEX TELEPHONY ACROSS THE STRAITS OF DOVER—
MARCH 31, 1931[18]

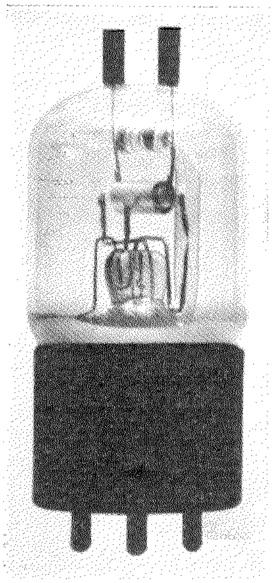
"Ultra-short wave radiotelephony and telegraphy, known as Micro-ray Radio, was demonstrated successfully between Dover and Calais on March 31, 1931, by the International Telephone and Telegraph Laboratories, Inc., of England, in cooperation with the Laboratories of Le Matériel Téléphonique, of France (also comprised in the I. T. & T. group of companies). The equipment was largely developed by French engineers in the Paris laboratories.

"The Micro-ray System employs transmitting and receiving antennae only 2 cm in length. It has a wavelength as low as 18 cm and requires power of only one-half a watt.* . . . The conversations exchanged between Dover and Calais were of high quality and well up to the standard of the best telephone transmission."

* * *

"The *Electrical Review* (April 10, 1931) under the caption 'Short Wave Radio Telephony,' in connection with the Micro-ray, commented editorially:

" 'One of the major problems of radio communication today is the crowded condition of the ether. Indeed, the bogey of congestion is so menacing that serious attempts are being made internationally to evolve some workable scheme of virtually rationing frequencies, whilst it has also provided the impetus to explore the possibilities of the shorter wavelengths. The use of the 5- to 50-metre range is satisfactory for long distance commercial communication, but, while the directive properties of short waves tend to simplify the avoidance of mutual interference, practical difficulties of application unfortunately increase progressively with increase of frequency. So acute did the situation become as to induce investigation even within the range of three metres, below which known technique does not appear to have been attended with any substantial degree of success. What was seemingly needed was some radical change in method, and it was an advance of that magnitude which was demonstrated successfully last week . . . as the culmination of work commenced about a year ago in a new field—so different from the existing one as to justify another name. Subject to entirely different conditions and necessitating a technique of its own, the extreme simplicity of the equipment and its ridiculously small power requirements mark a new epoch in the art of electrical communication.' "



Micro-Ray Oscillating Tube.

* * *

"A distinguished group of officials of the British Government and Military and Naval Attachés from various countries, leading scientists, and representatives of the press attended a demonstration at Dover while a similar group of French Government officials and guests came from Paris to Calais to participate in the demonstration."

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* Radiation emitted from the antenna was concentrated into a very sharp beam by means of the main paraboloidal reflector. The gain of this reflector alone was of the order of 28 db; it became 33 db when the additional reflector (spherical) was added to the system.[20]

* * *

Following the demonstration mentioned above, an order was received for a permanent link operating between Lympne, England and St. Inglevert, France, a distance of 56 kilometres.

In July, 1933, an article,[19] mainly theoretical, was published on the production and utilization of micro-rays. The main property distinguishing these rays is that use may be made of phenomena which are now commonly regarded as optical, such as reflection, refraction and diffraction.

This link, the first of its kind in the world and used commercially until interrupted prior to the war, employed positive grid triodes both at the transmitting and receiving ends. The two extremities of the oscillating electrode are connected to a transmission line leading to a radiating element (2 cm in length).

The Anglo-French micro-ray link, including the electro-optical system (transmitter and receiver units), micro-ray tube circuits, telephone and teleprinter equipment, was described in some detail in January, 1934.[20]

Micro-ray generators, receivers and aerial systems, together with results of propagation measurements, were described in April, 1936.[21]

(*b*) PROPAGATION TESTS WITH AND SUPERHETERODYNE RECEPTION OF MICRO-RAYS

Variations in signal strength had been noted on the 1,700 mc Lympne–St. Inglevert system and extensive tests were undertaken to ascertain what influence a change of wavelength would have on the amplitude and frequency of the fading phenomena.[22]

The type of tube used in the tests did not differ from that in regular operation on the Lympne-St. Inglevert micro-ray link. Theoretical considerations showed that the main factor underlying the design of micro-ray tubes for a specified frequency range is the wire length of the oscillating electrode. Further, for a given length of electrode wire, it is practicable to prepare a chart (Fig. 2[22]) giving as a function of the transmission line y the wavelengths which can be produced by the tube provided suitable oscillating conditions are obtained inside the structure.

The propagation tests were made on three wavelengths: 18 cm, 20 cm and 29 cm. Effects studied included the tide in the English Channel, local interference (of great importance) in front of the receiving reflector, interference caused by people walking along the cliffs, ships crossing the line of the beam at a certain distance, atmospheric temperature, humidity and wind conditions.

It was found by computation that a combination of two wavelengths would produce signals remaining above 18 db during the following time percentages:

18 cm+20 cm: 94%
18 cm+29 cm: 90%
20 cm+29 cm: 96.6%.

Another interesting result from the tests was the development of a new method for receiving continuous wave micro-ray telegraphy.*

For the reception of waves of frequencies in the neighborhood of 2,000 megacycles, simple detectors with or without reaction or superreaction usually had been employed. In 1937, a 17 cm superheterodyne receiver with stabilized intermediate frequency was described and its calibration as a signal strength measuring set discussed.[23]

Single Sideband Short Wave Telephone Links

As early as the period April, 1930–March, 1931, single sideband tests on short waves were carried out over the following three links:

Buenos Aires to Madrid
Local tests at Madrid (Pozuelo to Griñon, 80 km)
Madrid–Paris

Tests between Paris and Madrid showed that expected improvements over double sideband working were fully realized.

In July, 1931, the application of the single sideband system to short wavelengths was comprehensively discussed, as were the difficulties involved and the advantages to be realized. A possible commercial system was described, including the transmitter and receiver designs, and the problems of synchronization and improvement in signal-noise ratio.[17]

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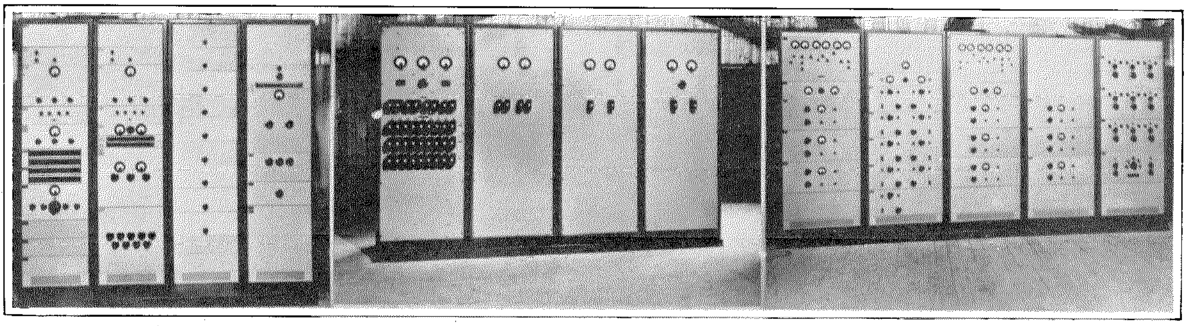
* *Brevet Français* 801,196.



Belfast-Stranraer 9-Channel Ultra-Short Wave Equipment. Stranraer End.

In October, 1933, the importance of reducing operating costs was emphasized inasmuch as only a few existing radio links were working at anything like full load. Further, on an existing typical link, either with light or heavy traffic, the single sideband suppressed carrier system could be expected to save about 87 percent of the valve replacement and 90 percent of the power costs. It was shown also that changing to single sideband working should be equivalent in signal/noise ratio to increasing the peak power of the transmitter about 16 times, thus greatly reducing the size of the transmitter. In addition, the single sideband system eliminates the chief cause of distortion, viz., that due to selective fading out of the carrier.

Among others, questions of independent stable oscillators at each end versus a pilot signal, and a simplified form of commercially applicable receiver, were considered. Mention also was made of several well known privacy schemes, then useless but promising in association with short wave working.

With the then existing equipment, the number of telephone channels available in the short wave band could be only slightly increased by applying the single sideband method, limiting factors being transmitter stability and receiver selectivity; it was pointed out, however, that in the future the limiting factor undoubtedly would be the frequency range occupied by the channels, i.e., the suppression of one sideband on speech circuits would become very important.[73]

Ultra-Short Wave Communication[24]

(*a*) Single Channel Radiotelephone Circuit Between Barcelona and Majorca.

(*b*) Nine-Channel Multiplex Radiotelephone Link Between Scotland and Ireland.

Comparison of the utility of wavelengths between 1 and 10 metres (300 and 30 mc per second) on the one hand, and 14 and 30 centimetres (2,100 and 1,000 mc per second) on the other was made in 1937. The conclusion was reached then that a most useful band for ultra-short wave working lies between 1 and 10 metres. The range between 6 and 3 metres was indicated as ideal for high-grade radiotelephone networks; and, the longer end of the ultra-short wave band seemed most promising for mobile units such as police cars.

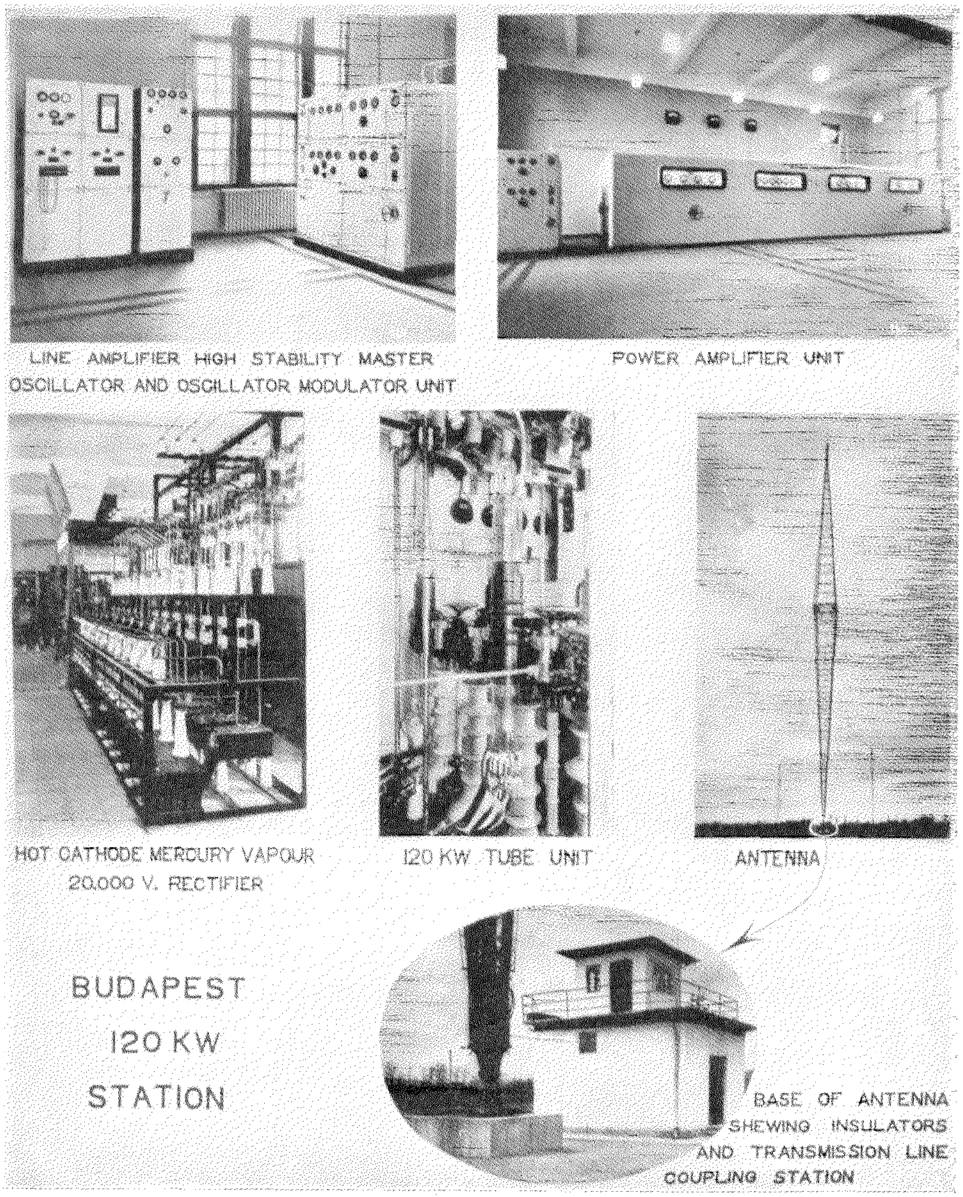
The first U.H.F. circuit interconnecting Barcelona and Majorca was opened in 1935. Work on additional circuits, operating in the 60 to 70 megacycle band and linking the three principal Balearic Islands (Majorca, Minorca and Iviza), was interrupted by the Spanish Civil War, but was completed immediately after its termination in 1939. In addition, a similar circuit was established between Algeciras, Spain, and Ceuta, Spanish Morocco.

The 1941 construction program of the Compañía Telefónica Nacional de España, incidentally, included the following U.H.F. links: (1) Malaga (Spain)–Melilla (Spanish Morocco); (2) Malaga (Spain)–Ceuta (Spanish Morocco); and (3) a second link Algeciras (Spain)–Ceuta (Spanish Morocco).

Broadcasting

(*a*) PRAGUE, CZECHOSLOVAKIA

Passing over earlier transmitters supplied by the International Standard group of Companies, such as those in England (Birmingham[74]), South Africa,[75] Denmark, Norway and Sweden,[76] and Iceland (where a 500 watt equipment initiated broadcasting at Reykjavik, the capital[77]), the Prague High Power Broadcasting equipment was described in January, 1932.[36] Its rating, according to C.C.I.R. definition, was 200 kw and at the time it probably was the most powerful broadcaster operating in Europe. It was designed to be capable of 100 percent distortionless modulation when delivering 120 kw carrier power to the antenna, i.e., the power which could be delivered by the valves in the final stage feeding the antenna was 480 kw. Modulation took


LINE AMPLIFIER HIGH STABILITY MASTER OSCILLATOR AND OSCILLATOR MODULATOR UNIT

POWER AMPLIFIER UNIT

HOT CATHODE MERCURY VAPOUR 20,000 V. RECTIFIER

120 KW TUBE UNIT

ANTENNA

BASE OF ANTENNA SHEWING INSULATORS AND TRANSMISSION LINE COUPLING STATION

Views of "Standard" 120 kw Broadcasting Station at Budapest.

place at low power with subsequent high frequency amplification.

The equipment was crystal controlled and yielded high quality reproduction with an overall power efficiency of the order of 22 percent.

(*b*) SOTTENS, SWITZERLAND

The Swiss Administration in 1930 decided to proceed with its plans for reorganizing its broadcasting service along modern lines. The system evolved gave listeners a greatly improved service including not only increased facilities for the interchange of programs amongst the principal cities of Switzerland, but also better reception through the installation of new transmitting equipment capable of meeting the highest standards then attained. Solution of the problem involved peculiar difficulties, partly because of the mountainous nature of the country.

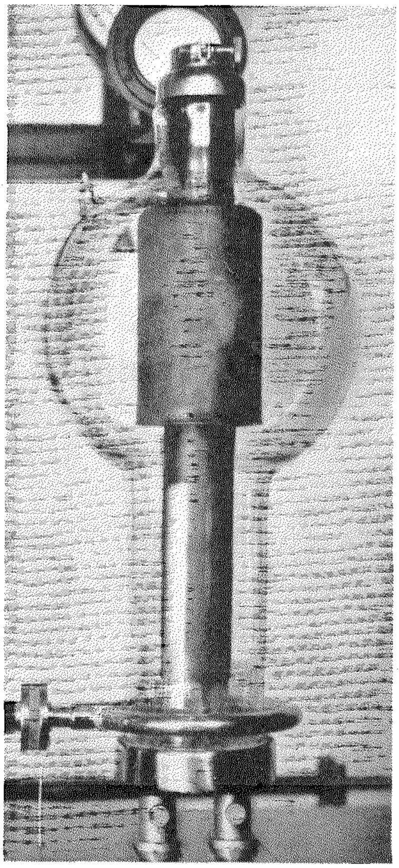
The stations erected were intended to serve the French-speaking and German-speaking parts of the country. A third high power station to serve the Italian-speaking part of the country was deferred.

The first of the new high power stations (Sottens),[78, 79] serving the French-speaking area, was inaugurated in March, 1931. The transmitter was designed to give carrier power into the antenna of 50 kw, which could be modulated 100 percent.

In January, 1935, the Swiss T.T. Administration placed an order to raise the power of the Sottens Transmitter to 100 kw and, also, to incorporate the latest broadcaster technique. In November, 1935, cutover of the entire extension was effected, the work of installation, adjustment and testing having been completed without interruption of the broadcasting service.[80]

(*c*) BUDAPEST (HUNGARY) AND KALUNDBORG (DENMARK)

The year 1933 witnessed extensive development of broadcasting services in Europe, and the International Standard Electric group of companies participated prominently by installing and putting into service eight new transmitters. The two largest, Budapest and Kalundborg, 120 kw and 60 kw, respectively, were described in 1934.[37] Both transmitters were built according to the same design, prepared by the I. T. & T. European Laboratories and were consequently very similar.



20,000 Volt, 250 kw, Hot Cathode Mercury Vapor Rectifier Tube—Kalundborg, 60 kw Transmitter.

A distinctive feature of both stations was the form of construction of the power amplifier equipment. Following the practice commonly adopted in the installation of indoor high voltage power plant, this amplifier equipment was installed in cubicles.

Interesting features included the use of a small number of valves of high power in the last stage; high efficiency mercury vapor rectifiers for the high voltage d-c supply; and the elimination of rotating machinery except for the single filament machine and the water pumps by the utilization of dry metal rectifiers and hot cathode mercury vapor rectifiers for the low power supplies.

In the 60 kw transmitter, there was one 120 kw valve with a second in reserve on each side of the push-pull circuit. In the 120 kw transmitter, two

120 kw valves were in operation and two were held in reserve on each side of the circuit, i.e., four valves were in operation with each valve having a reserve associated with it.

(*d*) ANTENNAE

The longest wavelength for which an antenna of the anti-fading type had been constructed was 549.5 metres: the antenna operating in conjunction with the above-mentioned 120 kw transmitter at Lakihegy, near Budapest.[38] Its height was 307 m (1,005 ft.); it was higher than the Eiffel Tower and it was, therefore, the highest structure in Europe and the tallest mast in the world. From observations and reports received, it appeared that the limit at which fading became apparent had been extended from a distance of 120 km for the case of the old T antenna to a distance of between 180 and 200 km. This was equivalent to more than doubling the service area of the station.

(*e*) BRITISH EMPIRE

The provision of a broadcast service from the home country to the distant regions of the British Empire for some years confronted the British Broadcasting Corporation with a problem of ever-increasing urgency.

Because of the distances involved, short wave working was necessary; the colonies and dominions, fortunately, could be divided into time zones: Australia (eight hours earlier than London); India (four hours earlier); Africa* (zero); and Canada (6 hours later).

This division necessitated separate treatment of each zone with concentration of radiation over selected areas. Important, also, was the use of different wavelengths for the various zones with due regard to special circumstances, such as broadcasts to Australia, the farthest away, in which case transmission must be effected through twilight conditions regardless of the path around the world selected. The aerial arrays, accordingly, were divided into five blocks, one for each zone, distributed around the transmitter building.

Due to the desirability of providing programs to the zones on alternative wavelengths, two transmitters were required with facilities for com-

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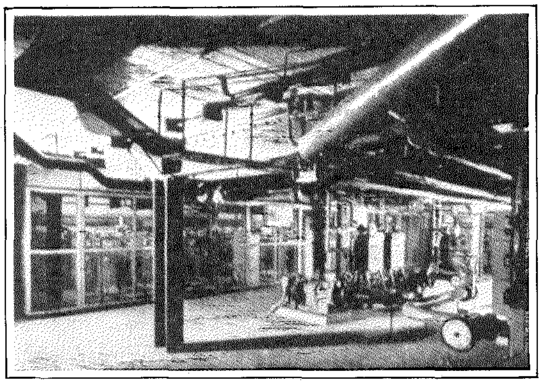
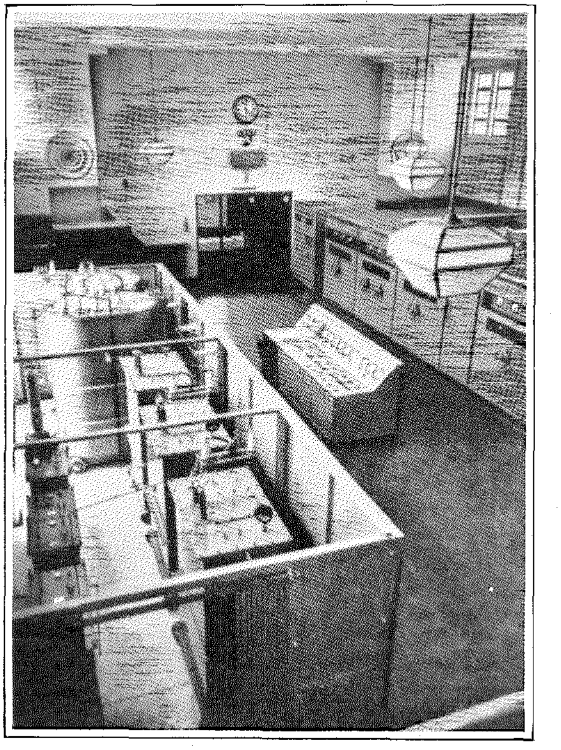
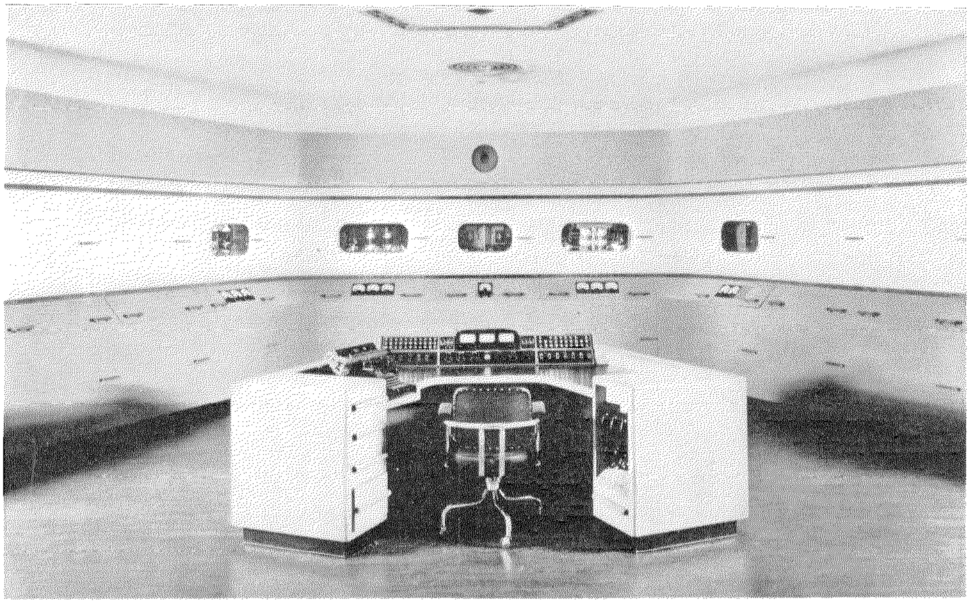
* Two zones.

The British Broadcasting Corporation's Start Point Transmitter. The view on the right shows the transmitter hall from the gallery, with the transmitter (right), control desk (center), and modulation transformer and plate feed reactors (left). Pictured below is the vault beneath the transmitter hall with valve-cooling water pumps and high tension enclosure in the background.

The Start Point, South Devon, 100 kw transmitter (285.7 m) and also the 20 kw Clevedon, Somerset, transmitter (203.5 m) were inaugurated simultaneously on June 14, 1939. They employ class "B" modulation with negative feedback so that the total harmonic content amounts to not more than 2.5 percent at 90 percent modulation.







Control Room at Columbia Island (near New Rochelle, New York) of Columbia Broadcasting System's New Station WABC. The main 50 kw broadcast transmitter is back of the center panels and the auxiliary 5 kw transmitter is behind the adjoining panels at the right. The station was inaugurated on October 18, 1941; the equipment was designed and constructed to CBS specifications by the Federal Telegraph Company, a unit of the International Telephone & Radio Manufacturing Corporation.

plete interchangeability between them and all the aerial arrays. The transmitters had to be capable of working over the band 13 to approximately 50 metres and to include arrangements for quick wave change on any of the broadcast allocations in this band.[81]

Each transmitter was tuned to operate on any of six wavelengths between 16.9 and 50 metres, these six bands being especially reserved for short wave broadcasting. Transmitters were capable of giving unmodulated carrier power of 12 kw, which could be modulated to 95 percent without appreciable distortion, i.e., the strength of the audio frequency harmonics introduced into the modulation envelope was 30 db below the fundamental modulating tone.

Of the five units in which the transmitting apparatus was housed, the first unit of each transmitter contained four crystal oscillators. Any one of these could be switched on to the transmitter with which it normally worked or, if desired, to the other transmitter; hence, each transmitter could work on one of eight frequencies. Frequency stability of these oscillators was approximately 40 parts to one million.

A moving ceremony, which evoked world-wide interest and in which communications played a unique rôle, took place in London on the 12th of May, 1937, in the Coronation of Their Majesties King George VI and Queen Elizabeth. From Broadcasting House the program was sent to the British Broadcasting Company's long and medium wave transmitters, used for the home service, and to the Empire short wave transmitters for broadcasting to the whole world. Radio facilities contributed by the I. T. & T. group of companies to this unique achievement included four B.B.C. Empire broadcast transmitters, two of which were specially expedited for use in the Coronation Ceremonies and were rated at 50 kw carrier power at 22 megacycles.[39, 83]

Notable additions to the British Regional network were the medium wave transmitters at Stagshaw[39] and Start Point,[82] supplied by Standard Telephones and Cables, Ltd., London. Both are rated at 100 kw and employ class B modulation with negative feedback.

(*f*) New Columbia Broadcasting System Transmitters

Uniquely located on a built-up island in Long Island Sound and providing optimum coverage of Metropolitan New York, the Columbia Broadcasting System's new 50 kw broadcasting transmitter, WABC, was inaugurated on October 18, 1941.[84] The illustration on page 155 shows a view of the control room.

Two new C.B.S. 50 kw international short wave transmitters, located at Brentwood, Long Island, were placed in service this year. They are being used in conjunction with specially designed directional antennae recently developed by the Mackay Radio and Telegraph Company for high efficiency beam service to South America and Europe (see Recent Telecommunications Developments section at the end of this issue).

(*g*) Final Stage Class "B" Modulation

As is evident from the preceding references, high power broadcasting in Europe developed fairly early due primarily to national rivalry; the power of broadcasting stations tended to increase progressively and was restricted only by technical limitations. Under those conditions the application of final stage Class "B" modulation proved especially useful and it was embodied in a number of transmitters prior to 1938; examples are transmitters at Melnik, Czechoslovakia, and at Stagshaw, England.

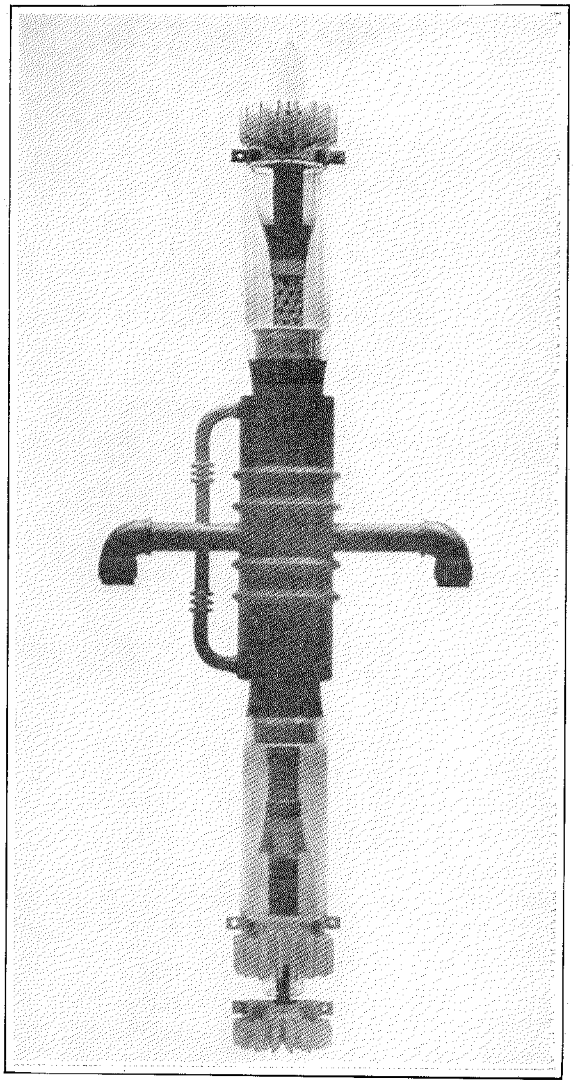
In April, 1938,[85] the performance of the Class "B" system was analyzed with particular reference to efficiency and fidelity. Mention was made of application to short wave transmitters where this system is particularly advantageous in comparison with alternative methods because of the wide flexibility which may be allowed in the adjustment of the high frequency stages. The problem of rapid wave change is greatly simplified by avoiding the necessity of critical adjustment of drive levels.

(*h*) 120 kw Vacuum Tube

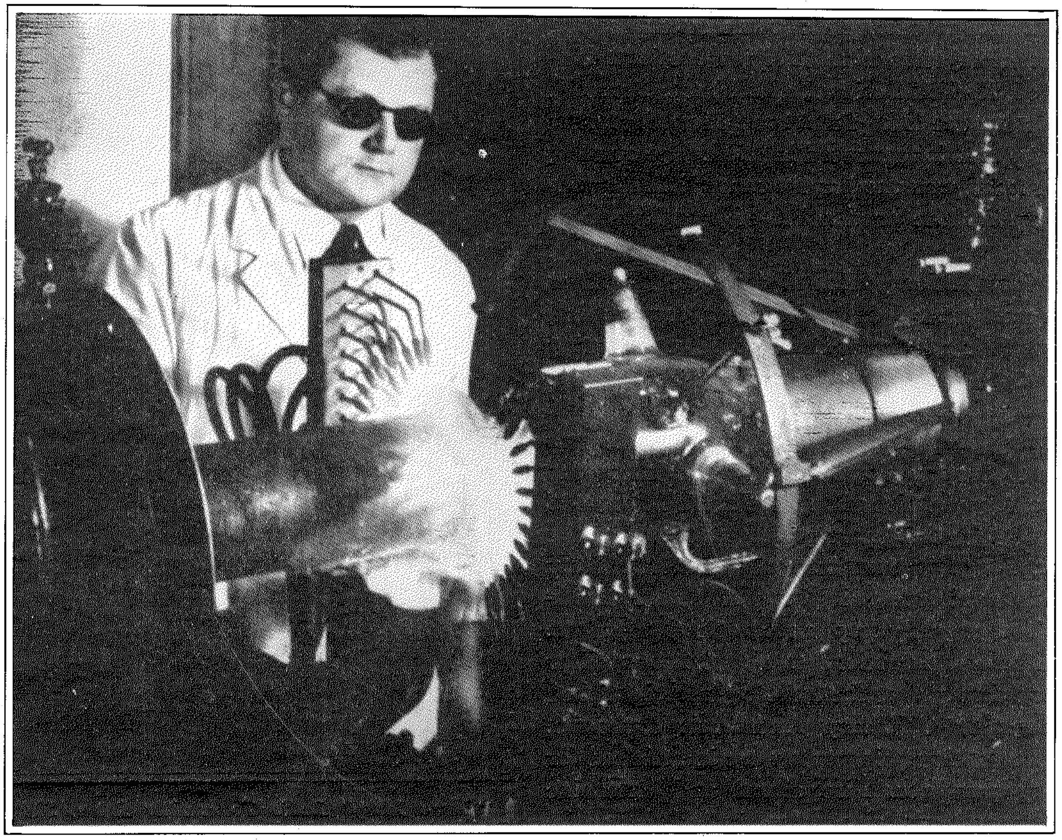
Rapid increase in high power broadcasting stations prior to 1933—certain stations radiating carrier power of 120 kw and reaching a peak power in the antennae of 480 kw with 100 percent modulation—prompted development and application of a 120 kw vacuum tube.[86] Experience had shown that the number of tubes, say of 40 kw capacity each, that could be used in parallel was limited and was attended with many difficulties, particularly the "Rocky Point Effect."

The tube developed possessed the following characteristics:

Heating power	5.4 kw
d-c anode voltage	20,000 volts
Maximum H.F. power as oscillator at 70% efficiency with $E_B = 20{,}000$ volts	=120 kw



120 kw Vacuum Tube (1933). Four such tubes in parallel in a broadcaster would absorb an average power of 750 kw and give a carrier wave power of at least 250 kw and a peak power of 1,000 kw.



Making the Glass-to-Metal Anode Seal on a 200 kw Vacuum Tube.

H.F. output power on test as oscillator at 70% efficiency with $E_B=25{,}000$ volts	=200 kw
Carrier wave power as linear amplifier, 100% modulation at 20,000 volts	30 kw
Probable filament life	6,000 hours

The development work showed that it seemed quite possible to develop and manufacture a satisfactory 200 kw tube. This, incidentally, has been accomplished and such tubes are now being manufactured by Standard Telephones and Cables, London, with the following characteristics:

Filament power	18 kw
Plate voltage as modulating amplifier	13,000 volts
Peak power per tube	400 kw

(*i*) HOT CATHODE MERCURY VAPOR HIGH TENSION RECTIFIER

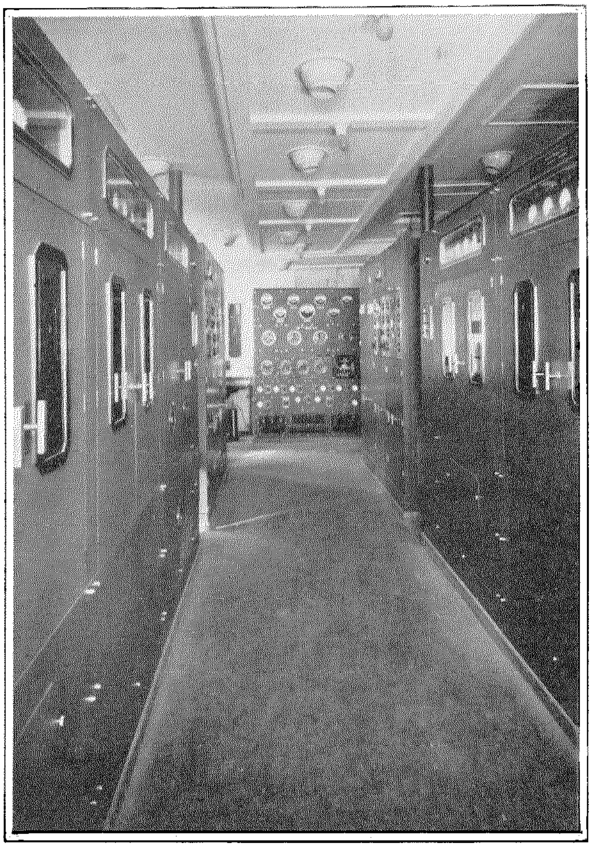
Due to the construction of higher power transmitters, the problem of providing efficient and reliable power equipment became more pressing. In October, 1936,[87] an important article was published, dealing with the respective characteristics and performance of the various types of high voltage d-c supplies for high power radio transmitters and making comparisons with hot cathode mercury vapor rectifiers. Characteristics of a series of hot cathode mercury vapor valves designed by L.M.T. Laboratories (Paris) were cited and the influence of the rectifier circuit characteristics was considered.

Subsequent developments showed that the description of a simple system for firing grid-controlled, hot cathode mercury vapor rectifiers was especially significant.

(*j*) STUDIO SYSTEMS

Following improvements effected in the transmission qualities of telephone cable systems, the policy of partial or complete centralization of studios was adopted rather generally in Europe. An outstanding example of such centralization is the studio system of the Belgian Institute National of Radiodiffusion (I.N.R.) at Brussels, supplied by the Bell Telephone Manufacturing Company and inaugurated in 1938. The system, then at least, was the largest center in existence anywhere for the production of broadcast programs.[88]

The installation included separate amplifier groups and control desks for seventeen studios, two dramatic mixer positions and five recording rooms, and, concentrated in a central control room, large banks of amplifiers for broadcast and monitoring purposes. Connections of the various studios to the outgoing line positions serving the stations for the French and Flemish zones of Belgium and the short wave station for the Belgian Congo, as well as to the dramatic mixer positions and recording rooms, were made through a step-by-step automatic equipment. Facilities for connections to about 200 monitor positions throughout the building were furnished by means of a Rotary Automatic exchange. Both automatic equipments were interlinked for checking purposes. Fire alarm and extensive signaling systems also were included in the installation.



"Queen Mary" Radio Transmitter Room, Showing the Transmitters Remotely Controlled from the Radio Operating Room 400 Feet Away.

Mobile Communications

(*a*) SHIP-AND-SHORE TERMINAL TELEPHONE EQUIPMENT

Commercial radiotelephony between Europe and America naturally directed endeavors towards the solution of the problem of maintaining telephone communications with the larger passenger vessels on the Atlantic route.

After referring to successful tests made between the International Telephone and Telegraph Laboratories and the SS *Berengaria*, Colonel A. S. Angwin (1930) mentioned an agreement to undertake a full scale experimental trial between the British Post Office and the International Marine Radio Company (an I.T. & T. associate). From these trials, commercial ship-shore service resulted; service to the SS *Majestic* was opened in February, 1930 (at first only for incoming calls).

Colonel Angwin indicated some of the special problems confronting the British Post Office, discussed choice of frequency and considered antenna arrays, the transmitter at the Rugby Station, the Baldock Receiving Station, land line connections, the prevention of singing, etc.[40]

(*b*) MOBILE RADIOTELEPHONY—A REVIEW (1932)

An interesting article[41] reviewed in general terms two-way radiotelephony on larger passenger vessels and smaller ships, including development, technical features and results obtained. Perhaps the earliest demonstration of marine two-way telephony was given in 1915 by Bell System engineers in connection with the U. S. Warship, *New Hampshire*. Following the development of short wave radio, telephony to and from ships became more practical and in 1929, short wave experiments were begun. Service on the British ship, *Majestic*, and on the American ship, *Leviathan*, was inaugurated early in 1930. These were followed by the *Olympic*, *Homeric*, *Belgenland*, *Empress of Britain* and *Monarch of Bermuda*. All were equipped with elaborate transmitting, receiving and voice frequency equipment, giving duplex service from a telephone booth or cabin on board the vessel.

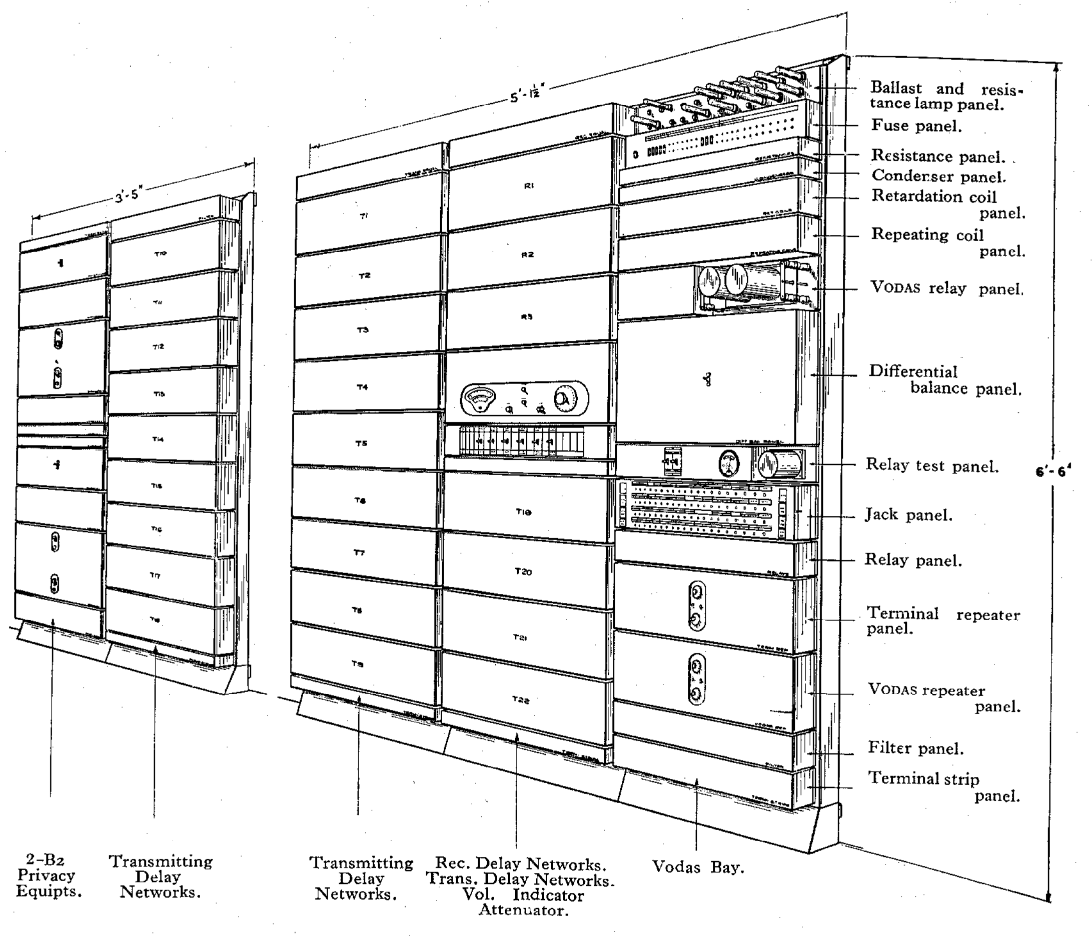
Remarkable results were obtained over extremely long distances during the world cruise of the *Belgenland* in the winter of 1930–31 and the *Empress of Britain* in 1931–32. Successful conversations were held with London when the ships were in the China Sea and with New York when at Alexandria.

With the object of reducing the number of necessary frequencies and simplifying apparatus, the International Telephone and Telegraph Laboratories conducted experiments in which the SS *Olympic* transmitted and received on the same frequency. Voice operated devices were used instead of the manually operated switch ordinarily employed on single wavelength systems.

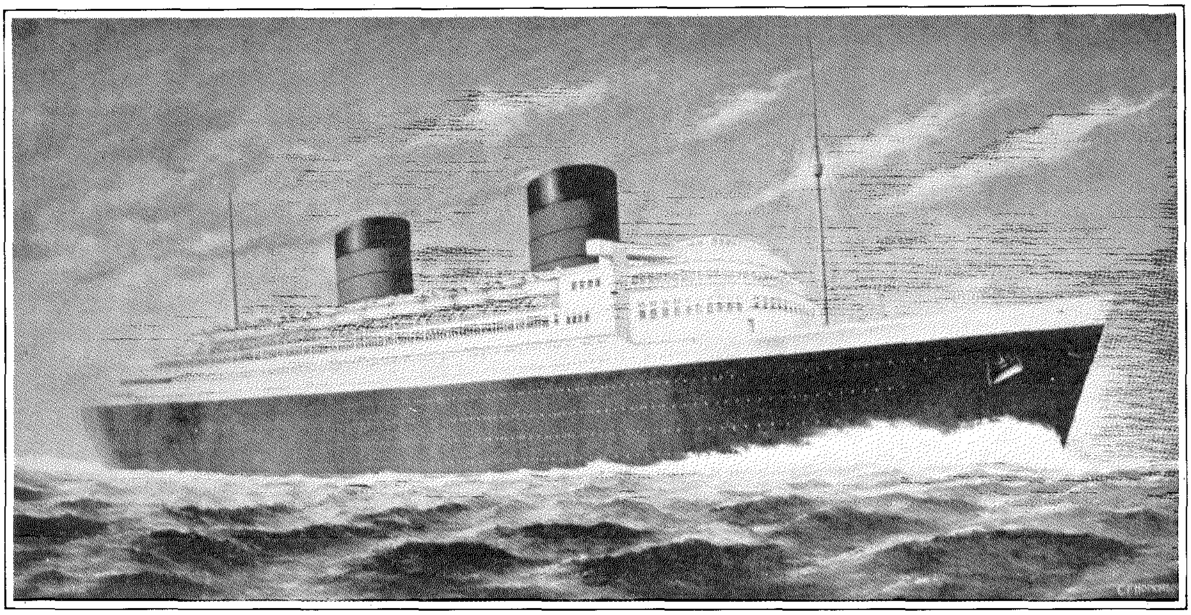
Two-way telephonic communication to airplanes, in Europe and in the United States, also was considered, as was radiotelephony to trains.

(*c*) CUNARD WHITE-STAR R.M.S. QUEEN MARY RADIO INSTALLATION

The *Queen Mary* installation, undoubtedly, is the largest and the most complete in the history of marine radio and was engineered to meet all


3'-5"
5'-1½"
6'-6"
Ballast and resistance lamp panel.
Fuse panel.
Resistance panel.
Condenser panel.
Retardation coil panel.
Repeating coil panel.
VODAS relay panel.
Differential balance panel.
Relay test panel.
Jack panel.
Relay panel.
Terminal repeater panel.
VODAS repeater panel.
Filter panel.
Terminal strip panel.
2-B2 Privacy Equipts.
Transmitting Delay Networks.
Transmitting Delay Networks.
Rec. Delay Networks. Trans. Delay Networks. Vol. Indicator Attenuator.
Vodas Bay.

"Queen Mary" Rack Assembly of Terminating Equipment. Its primary function is to prevent local interaction between the radio transmitter and radio receiver, despite their being deliberately coupled together through the subscriber apparatus and also unavoidably coupled together by induction from aerial to aerial.



"Queen Elizabeth." As in the case of the "Queen Mary," her radiotelegraph, radiotelephone and associated equipment were to be supplied and operated by the International Marine Radio Company, Ltd., London.

commercial telephone and telegraph traffic requirements, in addition to the usual navigational and safety services. Many recent advances in radio technique were embodied in the design of the radio system and several features previously associated only with land stations were applied for the first time to a marine radio installation.[89, 90]

Marine Radio Unit for Cargo Vessels. Developed by the Federal Telegraph Company.

On the maiden voyage, the heavy simultaneous demands made by telegraphy, telephony and broadcasting kept the four transmitters and at least four of the receivers in continuous operation for the greater part of the time the ship was at sea. Radiotelephone calls were completed from passengers' cabins to points as far distant as Capetown and Johannesburg, South Africa.

A complete voice operated switching device, the so-called VODAS, made it possible for a passenger to talk on the radiotelephone circuits from any one of the 500 telephones of the ship's two-wire telephone exchange, even under the most difficult radio conditions. Conversations could be carried on simultaneously with Europe or America; or, alternatively, the two independent circuits could be diverted to Europe or America.

The *Queen Mary* utilized 32 different wavelengths or frequencies. Her four main transmitters were on dial control direct from the operating positions located 400 feet from the transmitter room; change of frequency was accomplished automatically by means of a telephone dial. Complete secrecy of telephone conversations against the casual "eavesdropper" was assured through the inclusion of the frequency "wobbler."

The *Queen Mary* radio equipment was almost entirely manufactured by I. T. & T. associate companies, and was supplied, installed and operated by the International Marine Radio Company, Ltd., under contractual agreement with the Cunard White-Star, Ltd.

As in the case of the *Queen Mary*, it is pertinent to note that arrangements also were completed (1938) for the supply and operation by the International Marine Radio Company, Ltd., London, of the *Queen Elizabeth* radiotelegraph, radiotelephone and associated equipments.[91]

(*d*) New Marine Radio Unit for Cargo Vessels (1941)

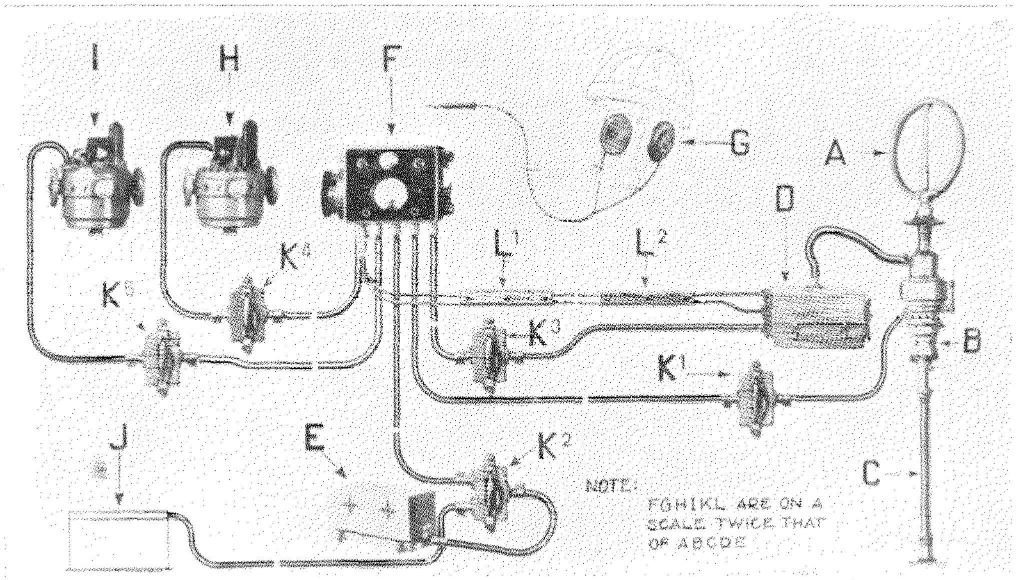
A recent development of the Federal Telegraph Company, a unit of the International Telephone and Radio Manufacturing Corporation, provides all necessary facilities for safety and communication purposes and combines, in a single compact cabinet, equipment which ordinarily comprises as many as twelve separate units. Installation is greatly simplified inasmuch as the unit is practically ready to "plug in" for power supply and antenna connection.[92]

Aerial Navigation

(*a*) Automatic Radio Compass

To extend in a simple way the effective visible horizon of an aircraft pilot, Le Matériel Téléphonique, Paris, in 1934, developed and constructed an automatic radio compass, which was the first automatic direction finder with 360° indication ever installed on board an airplane. The apparatus in principle is based on a receiving loop rotating at constant velocity around a vertical axis, permitting maximum reception each time the plane of the loop is oriented towards the transmitter.[42]

In France, both civil and military authorities submitted this radio compass to exhaustive tests and many airplanes were equipped with it. Actual service results were highly satisfactory and its use prior to the outbreak of the war in Europe was being extended not only in France but also in other countries, including Spain, Norway and Czechoslovakia. As mentioned above under In-



Airplane Automatic Radio Compass, Type R.C. 5.

troduction, this compass was introduced in the United States in 1937.

Combined with other instruments ordinarily carried in a plane, the automatic radio compass also was found useful for determination of drift, landing during bad visibility, etc.

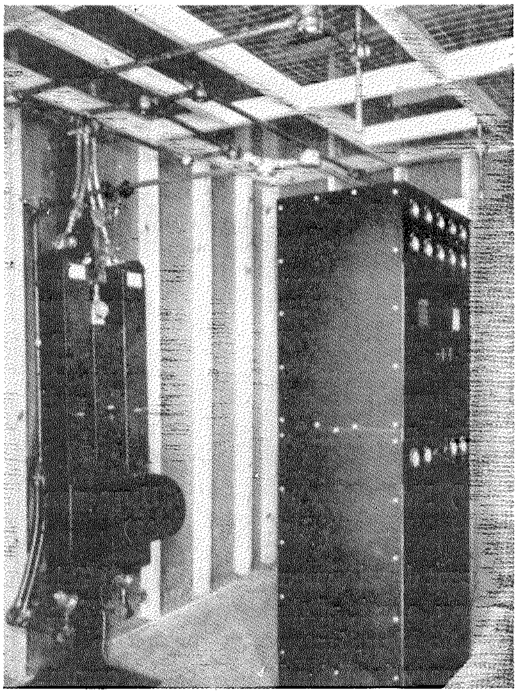
(*b*) NIGHT ERROR AND MOUNTAIN EFFECTS IN AERIAL NAVIGATION

The important phenomena of Night Error, Mountain and Polarization Effects in aerial navigation have been quite exhaustively studied by companies in the I.T. & T. group both in Europe and in the U. S. A.

In addition to the phenomena themselves, precautionary and corrective measures have been considered and procedures in airplane navigation with the radio compass and other devices discussed. A medium wave Adcock direction finder for airdromes, free from polarization error to a large extent, has been developed and installed in many places all over Europe. A semi-portable direction finder with an Adcock aerial system also has been briefly described.[43, 44]

(*c*) INSTRUMENT LANDING OF AIRPLANES

In view of the fundamental importance of the problem of landing airplanes under adverse weather conditions, International Telephone and Telegraph companies for some years have studied the problem of instrument landing. Their instrument landing equipment was installed at the Indianapolis Airport in 1938 for demonstration purposes. Modifications to meet specific requirements were introduced and, in July, 1940, an initial order was placed with the International Telephone Development Company (now the International Telephone & Radio Manufacturing Corporation) by the Civil Aeronautics Administration. This system, variously designated as the C.A.A., Indianapolis or International Telephone and Telegraph Instrument Landing System[45] provides the pilot with complete guidance to the airport runway, both horizontally and vertically. Through beams of ultra-short wave energy transmitted from highly directive equipment at the airport, the pilot by means of a conveniently placed instrument on his instrument panel is provided not only with the exact line of approach laterally to the concrete runway but also with the exact line of descent, when five miles or more away, to the runway so that the airplane settles upon the latter as in normal landing. Further, two "marker beacons" are provided along the line of approach to the landing runway: one indicates to the pilot arrival at a certain point, some distance from the runway, when he should be at a prescribed altitude and in line with the instrument landing apparatus so as to be headed directly for the runway; the other informs the pilot when he passes the boundary of the airport. With these facilities, pilots can land with consistent safety even when weather conditions are extremely difficult.



Instrument Landing of Airplanes. Interior of localizer building, showing transmitter and mechanical modulator.

(*d*) ULTRA-HIGH FREQUENCY LOOP ANTENNAE

The antennae considered were developed for two applications:

1. As elements in radiating systems of localizers and radio ranges used to guide aircraft;
2. As receiving antennae carried by aircraft.[48]

The unique property making them useful is that they radiate only horizontally polarized waves. Their directional characteristics are similar to those of a vertical dipole except that the waves emitted are horizontally rather than vertically polarized.

After calculation of the magnetic field of one radiator and of the four radiators forming the loop, as well as the radiation resistance, three types of ultra-high frequency loop antennae are described. Gain of loop antennae and radiation efficiency are discussed and applications of the three types cited. Methods of measuring radiation resistance also are indicated.

(*e*) AIRPORT COMMUNICATIONS AND AIRPORT ILLUMINATION

For what is perhaps the only comprehensive outline of the principal communications requirements of an airport and a description of some of the most modern equipment evolved to date, reference may be made to a recently published article. It deals primarily with LaGuardia Field, the Municipal Airport of the City of New York.[46]

Special Coaxial Cable Connecting the Eiffel Tower Television Transmitter with the Aerial at the Top of the Tower. The cable met rigid frequency characteristic and low attenuation loss requirements; it spanned the distance of over 380 metres between the transmitter and the aerial and weighed 12 tons.

An interesting airport illumination installation in Argentina has been described recently.[93]

Television

In March, 1937, Le Matériel Téléphonique, Paris, received an order for the realization of a 30 kw peak power television transmitter to be installed at the foot of the Eiffel Tower. The transmitter was placed in service December 25, 1938 and was then, and probably still is, the highest powered television transmitter in the world.[25]

The carrier frequency of the transmitter was 46 mc/s. Both sidebands were used, extending to 3 mc/s each side of the carrier frequency. The polarity of transmission was positive, i.e., a white image raised the transmitter power to the peak value, which was actually 35 kw (nominally 30 kw). The vision antenna surrounded the top portion of the tower for a few metres below the flag pole; the sound antenna was placed at the top of the flag pole.

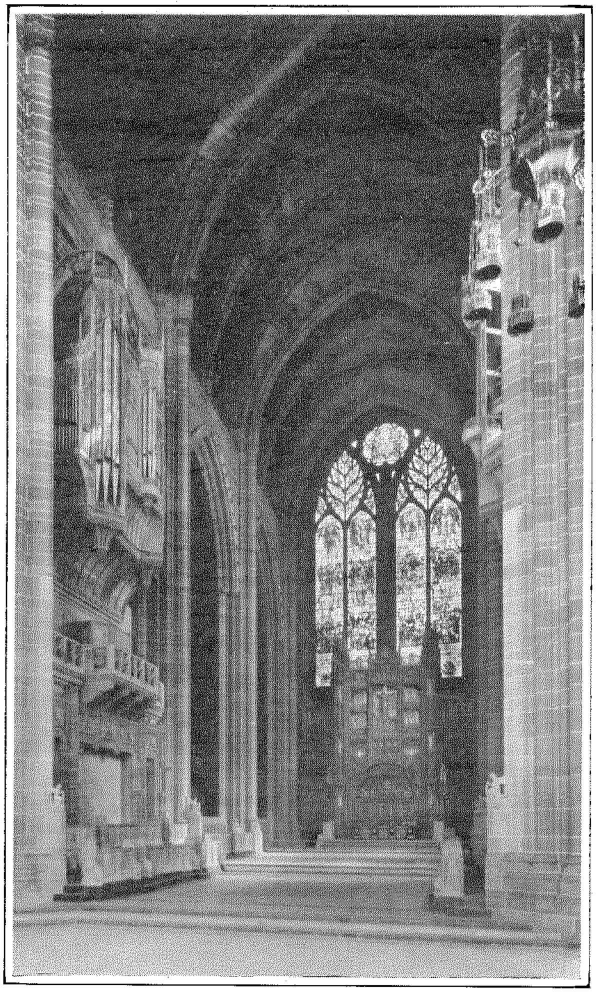
The French television standard, which was to remain in force up to July, 1941, called for 25 complete pictures per second, each picture containing between 440 and 455 total lines, the lines being interlaced so that the frame and flicker frequency was 50 per second.

The design of the output stage of the Eiffel Tower television transmitter is described elsewhere in this issue of *Electrical Communication.*

Public Address Systems

(*a*) LIVERPOOL CATHEDRAL

In the history of the Church of England, the opening of the Liverpool Cathedral was an important event; for, since the Reformation in the 16th Century, it was the first Anglican Cathedral Church to be constructed in the Northern Ecclesiastical Province. Liverpool Cathedral was planned to be the largest church in England; the portions opened in 1924 consisted of the East End, comprising Sanctuary and Choir, and the North and South Transepts. Some conception of the magnitude of this structure may be obtained from the illustration on page 164 when it is considered that the seemingly small electric light pendants are actually twelve feet in height and seven feet six inches in diameter.



Liverpool Cathedral: The Choir, Looking East. For the purposes of the Consecration Ceremony, loud-speaking projectors were mounted in the electric light pendants which are 12 ft. in height and 7½ ft. in diameter.

As a result of the success of the public address system in amplifying the address given by the Archbishop of York at the Consecration Ceremony, the Bishop of Liverpool decided that it would be necessary to have it installed in the Cathedral as a permanent fixture.[94]

The Cathedral has massive columns, marble floors and stone walls; some of the stones measure 5 ft.×5 ft.×4 ft. and weigh over three tons. Aside from the acoustical and other engineering problems that required solution, it will be appreciated that the installation of an invisible cabling system in a finished structure of this type was no easy task.

(*b*) 31ST INTERNATIONAL EUCHARISTIC CONGRESS, DUBLIN, JUNE, 1932

Preliminary investigations, equipment arrangements and results obtained with the vast, high quality public address system at Dublin in June, 1932, were described in April, 1933.[95] At the Pontifical High Mass on the closing day of the Congress, the congregation numbered approximately one million and occupied an area of about 200 acres. The equipment included street systems for reproducing speech and music over processional routes covering a distance of fifteen miles.

(*c*) 32D INTERNATIONAL EUCHARISTIC CONGRESS, BUENOS AIRES, OCTOBER, 1934

"Most comprehensively international of any biennial gathering of world Catholicism was the Thirty-Second International Eucharistic Congress held in Buenos Aires, October 10–14, 1934. This statement is made without reference to considerations other than the vast geographical proportions of the congregation which, unrestricted to local confines, listened to features of the program by virtue of the wire and radio facilities of the International Telephone and Telegraph group of companies and connecting services utilized for the transmission of words and music. Listeners included not only the multitude in actual attendance at the Congress but also, by means of an intercontinental broadcast hook-up, countless millions throughout South and North America, Europe, and other parts of the globe."[96]

(*d*) 34TH INTERNATIONAL EUCHARISTIC CONGRESS, BUDAPEST, MAY, 1938

A prominent Congress feature was the Boat Procession of the Holy Eucharist on the Danube when public address systems arrayed on both banks of the river transmitted the programs to the crowds aligned on its shores in devout adoration.

The Eucharistic Congress sound system, including all equipment and apparatus components utilized, was of impressively high quality and admirably adapted to the requirements imposed.[97]

(*e*) THE 1937 PARIS EXHIBITION

Original dispositions of public address systems were devised at the Paris 1937 Exhibition where loudspeakers were installed on eleven pontoons moored in the Seine and where music in combination with water, light and smoke added to the superlative esthetic effect of the Fêtes de la Seine.[97a] For its many contributions to the Paris Exhibition, including novel demonstration equipments and automatic attendance recording devices actuated by means of photoelectric cells, official awards were made to Le Matériel Téléphonique.

Machine Switching

(*a*) PARIS AREA

Study of the Paris telephone requirements started about a year before World War I and was resumed in 1924 or the early part of 1925. The unavoidable delay, however, gave the Administration the opportunity to study the methods and systems adopted by other administrations and to profit by their experience.

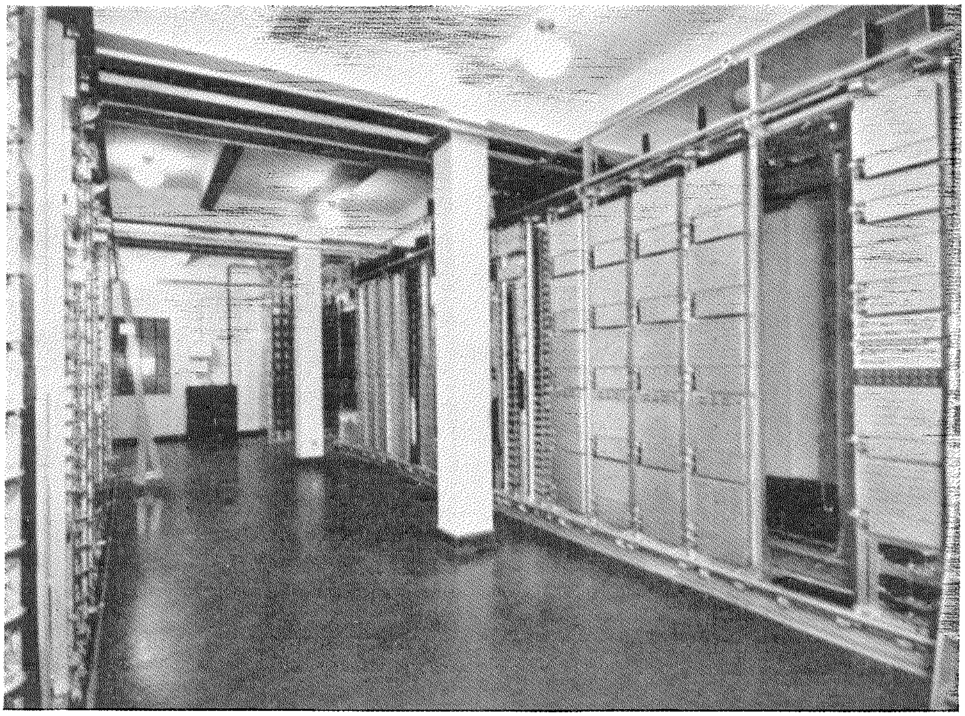
The French Government appointed two committees, one technical and the other general, to study the telephone requirements of Paris. After exhaustive explorations, the two committees unanimously chose the Rotary System for Paris, and, in October, 1926, the contract for the first four offices was awarded to Le Matériel Téléphonique. The contract carried with it the proviso that standard Rotary apparatus should be used throughout; also that the circuits should be designed by Le Matériel Téléphonique, and that the full responsibility for the successful operation of the system should rest with that company. The automatic system was planned to care for the city and the surrounding suburban areas with possible ultimate extension.[49]

On September, 22, 1928, Rotary Automatic was introduced into Paris by the cutting over of the Carnot office with 3,500 working lines.

The trunking plans of the Paris Network during the transition stage from manual to automatic working were described in 1934. To quote from the article:[50]

"To sum up, one can say that, bearing in mind the experience gained with thirty-two cutovers, up to date, the semi-automatic trunking plans utilized in Paris and suburban offices, in the transition stage between manual and full

Thirty-First International Eucharistic Congress, Dublin, June, 1932—O'Connell Bridge Altar and Part of Street Area Catered to by Public Address System.



7A-2 Rotary Equipment in the Callao Exchange, Compañía Peruana de Teléfonos Limitada, Lima, Peru.

automatic operation, have enabled the progressive conversion to automatic of the network without undue disturbance to the public, and also have improved the service in the offices where they are temporarily installed.

"From the economic standpoint, it is important to note that the gradual conversion of such an important telephone area has been accomplished without extensive modifications to the existing cable network due to application of the translator-registers associated with the equipments mentioned."

The conversion of the Paris City and Suburban areas was completed prior to the outbreak of the present war, and transformation of the Regional area had been progressing in all directions. Abnormal conditions prevented descriptive publications in English; the interested reader, however, is referred to articles which appeared in *Annales des Postes Télégraphes et Téléphones:* "Transformation en Automatique de la Région de Paris," by André Duprez, June, 1938; "Adaptation du Réseau Téléphonique de Paris à L'Exploitation Automatique de la Région de Paris," by André Blanchard, July 1938.

(*b*) ROTARY AUTOMATIC IN SWITZERLAND

In January, 1930, the last manual office in Geneva was replaced by an automatic office of the Rotary type, thereby placing Geneva with Zurich on an all automatic basis. In Basle, the banking center of Switzerland, Rotary Automatic equipment also was installed.[51, 52, 53]

Unusually interesting and highly satisfactory data involving service observations and maintenance results obtained by the Swiss Administration with Rotary Automatic equipment were published in 1931.[53] In the following decade, the progressive Swiss Administration greatly extended its network and installed the latest types of Rotary equipment so that similar data brought up to date doubtless would show even more favorable results.

Based on its experience with automatic operation both in city and rural services, the Swiss Administration undertook consideration of the automatization of the toll service. It is notable that the first step in the automatization of the toll plant, between the cities of Berne and Biel, was completed in 1930.[54]

The second stage was completed by the introduction in Basle of automatic toll service in 1933. A series of new features and operating methods, not previously utilized, were introduced; the equipment employed was the 7D Rotary System.

Subscribers had the choice of establishing their own connections by means of the telephone dial or to request a toll connection from the operator. Their quick recognition of the advantages of direct automatic selection was demonstrated by the fact that, within a few months after the introduction of the new system, 85 percent of all connections were thus established (Basle-Zurich and vice versa).

Metering also was accomplished automatically in accordance with prescribed zone charges and elapsed time.

(*c*) National Dialing in the Netherlands

The Netherlands Government Telephone Administration in collaboration with the municipal networks of Amsterdam, Rotterdam, and The Hague, prior to the invasion of Holland in 1940, had been carrying out a vast program of automatization of its telephone plant. Plans included the conversion to automatic operation of all manually operated local exchanges and the installation of equipment for handling long distance traffic on an automatic basis. Approximately 1,200 exchanges were involved.

On January 1, 1938, subscribers who were able to handle their calls on an automatic basis conconstituted 70 percent of the total number of lines connected in Holland. Exchange networks also had been grouped and cable plant provided to correspond with the division of the country into twenty rural districts or zones in line with long distance traffic requirements.[55]

Dialing service from the whole of the Haarlem Zone towards the Amsterdam Zone was inaugurated over 24 toll lines on July 1, 1937. Shortly thereafter, it was necessary to increase these toll lines from 24 to 30 due to stimulation of traffic through the provision of automatic facilities. Opening of the automatic service from the Amsterdam Zone to the Haarlem Zone occurred on February 28, 1938.

(*d*) Signaling Systems on Toll Lines

Introduction of full automatic equipment in rural and suburban exchanges and the rapid progress in Europe of subscriber-to-subscriber toll dialing necessitated a departure from the familiar methods of direct current signaling in use in local telephony.

A new type of 50-cycle signaling system was developed by the Laboratories of the Bell Telephone Manufacturing Company, Antwerp, with low sending voltage and current. Early in 1936 a complete demonstration of the Rotary Automatic Toll System was made in Berne for officials of the Swiss P.T.T.; the demonstration equipment subsequently was installed in Zurich, Lugano and Faido* in order to test the 50-cycle signaling system under service conditions.[56]

The trial included:

(*a*) An outgoing toll exchange: Faido;
(*b*) A tandem toll exchange: Lugano;
(*c*) A second tandem toll exchange: Zurich;
(*d*) A terminating toll exchange: Zurich;
(*e*) A local automatic exchange;
(*f*) Six standard 2-wire repeaters.

Faults encountered were not greater than in the average local network.

International voice frequency signaling and dialing in Europe, because of its special importance in the interconnection of national communication systems, was a problem to which the C.C.I.F. had been devoting considerable attention prior to the outbreak of war in 1939. The development aspects involved were rather exhaustively discussed in this journal in July, 1939. Summarization here cannot be attempted because of the complexity of the subject; listing of the contents of the article[57] may be of interest.

1. Introduction.
2. Importance and Necessity of Voice Frequency Signaling.
3. Comparison with d-c and other a-c Signaling Systems.

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* Zurich is in the northern part of Switzerland; Lugano near the southeast border; Faido is at an intermediate point.

4. Interference between Voice Frequency Systems.
5. Recommendations to Avoid Interference between Voice Frequency Systems.
6. Time Variations Associated with Voice Frequency Signals.
7. Choice of Frequency for the Prefix Signal.
8. Voice Immunity Tests.
9. Determination of Length of Prefix.
10. Efficiency of the Guard Circuit.
11. Considerations Controlling the General Arrangement of the Voice Frequency Code of Signals.
12. Signal Code Timing.
13. Transit Working.
14. Summary of Research Work in Progress and Questions Awaiting Consideration.

Appendix No. 1—Glossary of Terms.
Appendix No. 2—Translation of Proceedings of 3d Commission of Rapporteurs, Oslo, June 1938.
Bibliography.

(*e*) 7A-2 ROTARY AUTOMATIC TELEPHONE SYSTEM

The cutover of 12,000 lines of the new 7A-2 Rotary equipment in Bucharest, Rumania, in 1933, marked the completion of an extensive program calling for the complete redesign of the 7A Rotary System. The following résumé conveys an idea of the new features and the extent of the changes introduced.[58, 59, 60]

Apparatus and Equipment

1. A redesigned line finder, selector and sequence switch, together with associated mounting bays, permit a substantial saving in space occupied, lower manufacturing costs and reduced maintenance expense.
2. New manufacturing processes make the characteristic Rotary construction features more robust, and new finishes make both apparatus and wiring more impervious to humid atmospheric conditions such as obtain in tropical climates; an improved method of shielding also is used to serve for fire protection, together with a new type of switchboard wire which possesses greatly improved fire resisting qualities.
3. Radically improved methods for fusing and power distribution greatly facilitate maintenance and reduce first costs. To these same ends the tone and alarm distribution systems have been modified.
4. A new style of switchrack construction permits of considerable saving in space without sacrifice of rigidity which has always been a feature of the Rotary system.

Switching System Facilities and Circuits

1. While the new switches and circuits are considerably changed, the requirement that they must interwork with existing networks with a minimum amount of change was constantly kept in mind. As a result, extensions to present offices and networks can be made as readily as though the present system were continued in use.
2. Improvements have been made in the new circuits and apparatus regarding operating times and limits, voltage range and other similar factors with the result that the operating ability of the Rotary equipment has been further improved. A notable change of this type is the new selector commutator which produces an unusually uniform impulse and should require practically no maintenance.
3. The new switching scheme employed for the line finder makes use of a new 200 point switch together with special alternative outlets for completing overflow traffic during the peak load periods. Another important switching change has been made between the cord and register circuits, permitting considerable saving in equipment costs.
4. Provision is made in the selector switches to provide for converting two adjacent levels into one common group of trunks. This feature raises the number of trunks in one common group from the previous figure of 30 trunks to a new maximum of 60 trunks which should be more than sufficient for present or future requirements.
5. In redesigning the system, full recognition was given to the present tendency towards long distance dialing, CLR and other special toll services, together with the increasing demand for simplified facilities for interworking with rural and suburban automatic networks. Provision has also been made for connecting with other types of automatic systems and manual exchanges with a minimum amount of expense.
6. Time, zone and multi-metering features have been developed as an integral part of the system and can be applied to all conditions.
7. Miscellaneous service features, such as paystations, party lines (with or without metering), direct working with apartment house satellites, and other similar arrangements can be provided to meet all requirements.
8. Traffic recording and maintenance which already are noteworthy features of the Rotary system have been further simplified. Included in these improvements are centralized service observing and special facilities for the detection of malicious calls, automatic faulty line indication and delayed back release.

(*f*) 7D ROTARY AUTOMATIC TELEPHONE SYSTEM

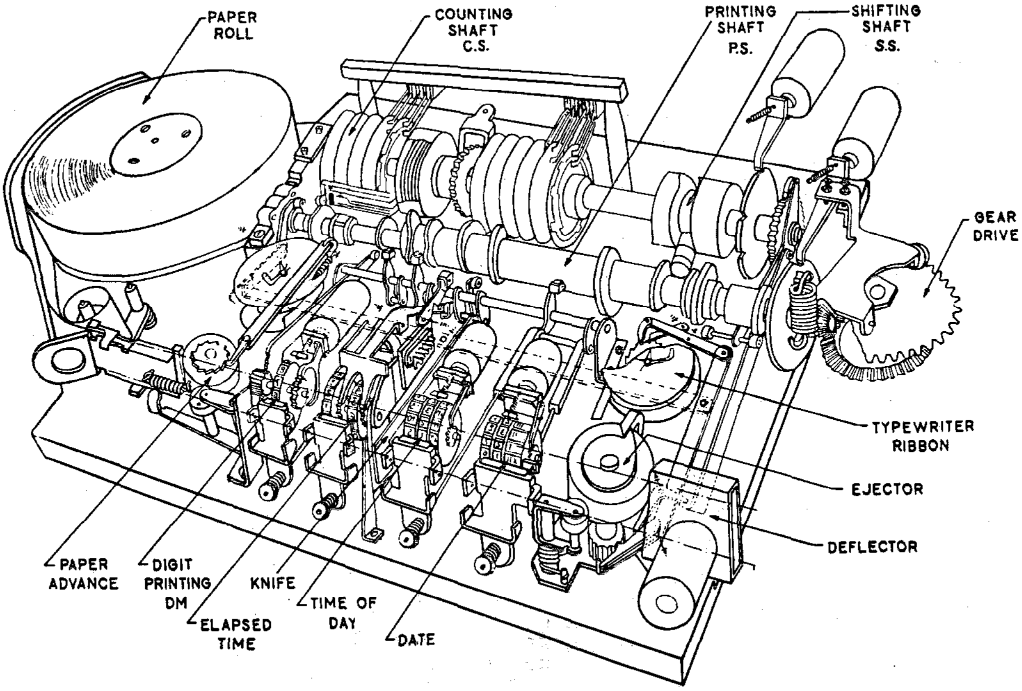
By 1935 the Rotary System had been installed in many of the principal cities of Europe: Oslo, Copenhagen, The Hague, Brussels, Antwerp, Liége, Paris, Zurich, Basle, Geneva, Madrid, Barcelona, Bucharest and as far afield as Istanbul, Cairo, Shanghai, Rio de Janeiro, Lima and Mexico City. In round figures, 1,621,000 lines had been provided (now well over 2,000,000) in 23 different countries and in 642 different exchanges.

A comprehensive redesign of the equipment intended for use in small communities was described in 1935.[61] Among many other features, it included means for the automatic interconnection over a wide area of subscribers in small communities. The largest rural area served by the 7D Rotary System was situated in the neighborhood of Zurich and comprised 50 offices with a total of 14,800 lines. This area worked on a full automatic basis with the 7A Rotary multi-office area of the city of Zurich. The complete Zurich district thus comprised approximately 60,000 subscribers' lines interconnecting on a full automatic basis. Subscriber-to-subscriber dialing between Basle and Zurich being in operation, plans for early extension to rural subscribers had been completed (April, 1935). Their realization provided for the full automatic interconnection of over 100,000 lines of Rotary equipment installed in 124 different exchanges, the two most distant being separated by 100 km; the area covered more than 1,500 square kilometres.

Automatic Ticketing of Telephone Toll Calls

A new telephone facility known as Automatic Toll Ticketing, the first of its kind anywhere, was placed in public service on December 7, 1936, in the town of Bruges, Belgium.[62] This event marked a distinct advance in the evolution of communication systems.

Automatic Toll Ticketing demonstrated the possibility of offering to a telephone subscriber the advantages of full automatic dial service, toll as well as local, previously fully satisfactory only on local service. It makes available an in-



Perspective of One Form of Automatic Toll Ticketing Printer. It derives its energy from a common power drive, following regular Rotary System practice.

dividual and complete printed record of every toll call without participation by any human agency other than the calling and called subscribers.

Without toll ticketing, it is necessary in the case of toll or long distance calls to resort to the preparation of toll tickets by an operator, a cumbersome and time consuming procedure, or the introduction of time and zone metering, furnishing merely an integrated record of unit charges and often involving burdensome equipment alterations. Automatic toll ticketing, on the other hand, can usually be introduced with minimum modification of existing systems.

The automatic printing register itself was described in April, 1937;[63] applications of automatic ticketing in step-by-step systems and in long distance telephone connections were described in January, 1939[64] and January, 1940.[65]

Private Automatic Exchanges

A satisfactory type of PABX for use in sizable establishments must be capable of providing the following facilities: calling in an attendant; call-back; transfer of calls; night, restricted, tie-line, conference, preference calling, code and fire services. Such exchanges may embody provisions for the connection of a thousand or more stations and any required number of trunks to the public exchange.[98, 99]

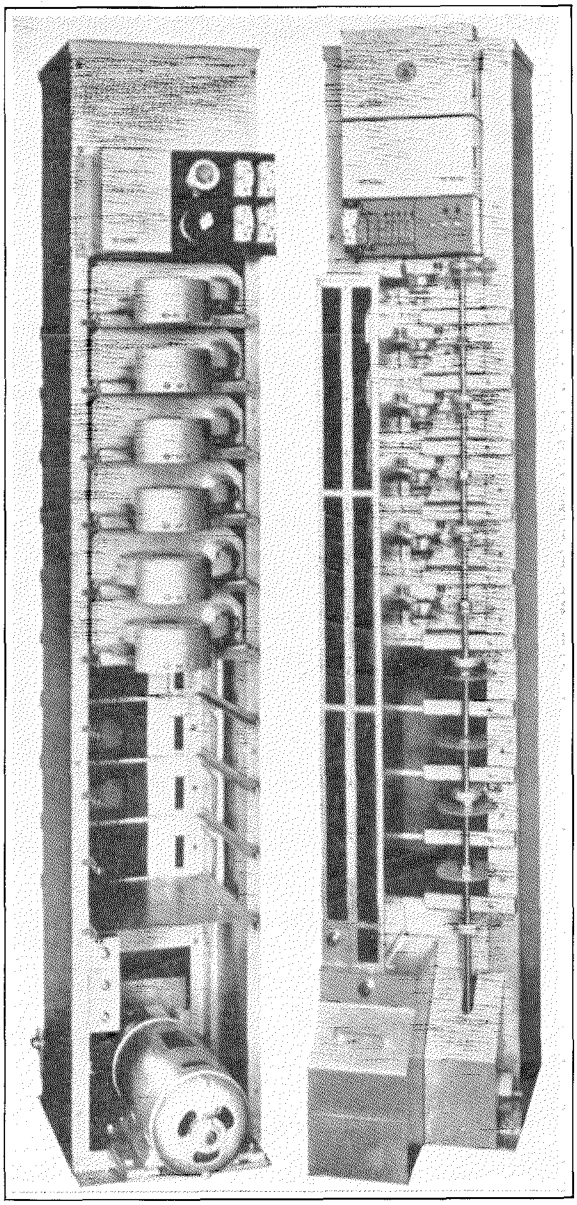
An outstanding example of a PAX was that of the great Danish newspaper, Politiken. To provide the reliability and speed necessary in handling last minute news events, a board of the Standard Electric 7D type with its simple and robust apparatus, as well as its high speed 100-point selector, was chosen.[100]

An unusual installation[101] was that of the Belgian Administration for Civil Air Transport, operating four airports located at Brussels, Antwerp, Ostend and Zoute. Regular national services, both freight and passenger, in addition to considerable international traffic, were handled through them.

Private exchanges interworking amongst the four airports involved special problems, due partly to their wide separation and to the necessity of equipping the loaded cable pairs with voice frequency repeaters. Inasmuch as ordinary d-c dialing could not be used, it was found necessary to resort to 50 cycle signaling, the principles used in automatic long distance dialing being applied.

Transmission

The facility and speed with which communications can be obtained over local, continental and intercontinental networks bear proof of the outstanding achievements made possible through organized research and development in the art of speech and signal transmissions. Progressing from open wire systems to cable for local tele-



Automatic Toll Ticket Printer Bay, Front and Rear Views.

phone networks, loaded cables, phantomed circuits, vacuum tube repeaters, 2- and 4-wire systems, 1- and 3-channel carrier systems, today broad band carrier systems play a predominating role. Prominent in the development of the broad band systems were improved molybdenum-permalloy dust coils, crystal filters, feedback amplifiers and dry metallic modulators. These developments will be considered in an article on transmission which is scheduled for early publication in *Electrical Communication.*

Many articles in this journal have been devoted to substantial additions to the world's telephone wire and cable network. Their importance will be appreciated when it is considered that wire and cable networks, in addition to their fundamental value in the communication services, are indispensable to international connections on a subscriber-to-subscriber basis inasmuch as radio links, despite their essential nature, must in general be considered solely as adjuncts to local, national and international wire networks.

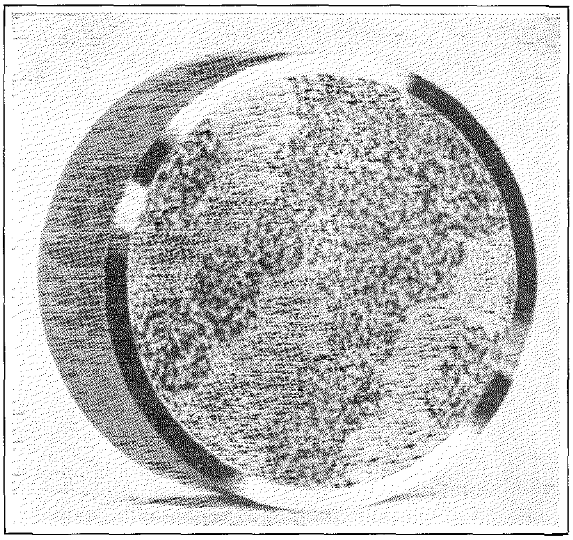
Loaded and Repeatered Cable

It is interesting to note that the first toll cable installation described in *Electrical Communication* (1923)[102] was that of the first telephone toll cables installed in Japan. They were the Osaka-Kobe and Tokyo-Yokohama cables (each approximately 22 miles in length), and consisted of 52 quads, loaded throughout with medium heavy loading for side and phantom circuits.

Important in connection with future international telephony was the new Simplon tunnel cable, connecting Switzerland and Italy, which was completed in 1922.[103] Great care was required in its design to avoid interference from power circuits in the tunnel and also to ensure a standard of performance satisfying not only immediate requirements but, in addition, future requirements, such as would be imposed by the introduction of telephone repeaters.

The Milan-Turin-Genoa underground cable installation was begun in December, 1922. It provided 2- and 4-wire physical and phantom circuits, and was a loaded and repeatered cable.[104] Plans provided for connection at Casteggio of future projected cables.

The success of the Milan-Turin-Genoa underground cable installation was demonstrated by a great increase in traffic. After the completion of the contract, a study was made of a main cable system extending through the whole country and also connecting the rest of Europe via Switzerland and Austria. Subsequently, an order was placed for a complete system of loaded and repeatered cables from Chiasso and Tarvisio on the Swiss and Austrian borders of Italy, to Naples, via Bologna, Florence and Rome.[105]



2,400 Pair "Loop" Telephone Cable (4,848 Conductors in a Single Sheath). It has the largest number of pairs ever manufactured commercially.

Sweden was the first country in Europe to obtain a completely up-to-date cable of the magnitude provided by the telephone cable between Stockholm and Gothenburg[106] (1923), a distance of 458 km. It was a lead covered but unarmored quaded cable loaded for side and phantom circuits and provided with repeaters.

Factors accelerating expansion of the Swedish cable systems included railway electrification and consequent interference with open wire telephone circuits, rapid growth of telephone traffic and economic considerations. In the Stockholm-Norrköping[107] telephone cable system, projected to form part of the Stockholm-Malmö cable, a later system of loading and also, for a certain type of circuit, the four wire transmission system was adopted. Medium-medium loading was used on the Stockholm-Gothenburg cable; on the Stockholm-Norrköping cable, medium-heavy and extra light loading were chosen, thus obtaining an increase of the cut-off frequency. When the cable route was comparatively near to the railway line, the cables were armored with two layers of iron bands.

The Stockholm-Malmö system included circuits of the following types:

4-wire circuits with extra light loading for long international lines;
4-wire circuits with medium-heavy loading for other international and long inland lines;
2-wire circuits with medium-heavy loading for the remaining lines.

The Stockholm-Gothenburg[108] and the Stockholm-Malmö[109] railway cables, totaling 458 and 936.3 km in length, respectively paralleled the rail routes, and provided the latest technique then developed. Their design involved special problems of induced voltages and interference with speech currents.

In an article on the London-Glasgow trunk telephone cable[110] the London-Derby No. 2 cable, which represented the most modern practice in telephone cable manufacture and installation, and the repeater stations between London and Glasgow, were described. This cable was of particular interest because of the density of traffic handled and the segregation of the 4-wire circuits in the Up and Down groups, while the 2-wire circuits formed the center of the cable. Incidentally, the London-Fenny-Stratford section paralleled the old London-Birmingham loaded cable; its completion by a predecessor organization of Standard Telephones and Cables, Ltd., was cited in 1915 as marking the first stage in the realization of the scheme for connecting London and Liverpool by means of an underground telephone cable.[111]

An outstanding event from the viewpoint of European international long distance telephony was the completion in September, 1926, of the Paris-Strasbourg Cable,[68] 494 km in length. It traverses several important industrial areas, such as Champagne, Lorraine and Alsace: the first famous for its wines, the second for its heavy industries and the last for its agricultural products. In addition to providing communication betweeen Paris and these areas, international telephone traffic was dealt with by connections from Paris to England and Belgium; northern and central Germany, via Nancy and Strasbourg; and Switzerland and Italy through Selestat.

On the main route between Paris and Strasbourg, two sizes of cables, both with telephone and telegraph quads were employed. Telegraph quads were in the center of the cable and screened from the telephone quads by means of a layer of aluminum tape. From Paris to Selestat (450 km) the cable consisted of:

66 quads of 0.9 mm conductors } for telephone working
16 quads of 1.3 mm conductors }
12 quads of 1.3 mm conductors—for telegraph working

and, from Selestat to Strasbourg, (44 km) of:

42 quads of 0.9 mm conductors } for telephone working
22 quads of 1.3 mm conductors }
7 quads of 1.3 mm conductors—for telegraph working.

The principal items of repeater equipment at each of the seven repeater stations are listed in the table below.

Other interesting toll cable systems described in this journal were those of the Danish Telegraph Administration's network,[112] all the later cables including specially screened, light-loaded circuits for the Broadcasting Administration;

	4-Wire Repeaters		2-Wire Repeaters		Voice Frequency Ringers		4-Wire Terminating Sets	
	Initial	Ultimate	Initial	Ultimate	Initial	Ultimate	Initial	Ultimate
Paris	75	84	..	..	94	140	69	103
Viels-Maisons	31	79	36	51	..	..	..	..
Chalons	75	84	..	..	5	7	..	..
Stainville	31	79	36	51	..	..	3	3
Nancy	75	89	1	7	22	24	8	8
St. Die	30	63	37	46	4	9	4	20
Strasbourg	26	26	5	5	31	32	25	26
Totals	343	504	115	160	156	212	109	160

and the Hong Kong-Canton toll cable,[113] part of which comprised a submarine section across Hong Kong Harbor from Hong Kong to Kowloon, which was protected by brass tape and heavy steel armor, manufactured in one length of 2,200 yards and balanced in the factory of Standard Telephones and Cables, Ltd., London.

The Czechoslovakian Administration realized early that a really efficient long distance telephone service between chief centers would aid materially in the development of the Republic. Plans for a modern toll cable network provided for national as well as international service.[114] As an example of international cooperation and coordination, it may be stated that the orders for repeater equipment and loading coils were placed on Standard Electric Doms A Spolecnost, Prague; the repeater equipment was manufactured by the Bell Telephone Company, Antwerp; the loading coils were produced by Standard Telephones and Cables, Ltd., London, The Bell Telephone Manufacturing Company, Antwerp, and Le Matériel Téléphonique, Paris, all associated companies of the International Telephone and Telegraph Corporation. The cable was of "Standard" type with the exception of sections crossing the Austrian and German frontiers, and was manufactured and installed under advice of the International Standard Electric Corporation.

VOICE FREQUENCY TELEGRAPH SYSTEMS

In the April, 1925, issue of *Electrical Communication* a voice frequency telegraph system was described;[115] it gave good service for a number of years, but improvements in the communication art and in apparatus design and equipment practice offered opportunities of developing a more effective system[116] intended primarily to provide up to eighteen 2-way telegraph channels on a 4-wire cable circuit. At the time the description was published (1932), two systems of this type, comprising 12 channels, were already in operation on 4-wire circuits in Great Britain and France. The system is applicable to various types of circuits, the most usual being the 4-wire loaded and repeatered cable circuit. When operated over a 2-wire circuit, the number of channels obtainable is reduced by half since in this case different frequencies are used for transmission in the two directions.

1- AND 3-CHANNEL CARRIER SYSTEMS

The first carrier systems outside of the U. S. A. were installed in Brazil (1924) and Australia (1925).[66] Australia was the first to use the C-2-F Carrier System to provide long haul single channel carrier systems for connecting Melbourne with important farming centers in Victoria and South Australia.[67] This marked a further step towards the Telephone Administration's goal of providing a highly efficient nation-wide telephone service. That this task represented a considerable undertaking will be appreciated when it is considered that Australia is 25 times as great in area as England and its population is less than that of London.

"If you speak from New York to Brisbane, from Oslo to Madrid, from Bucharest to Buenos Aires, or from London to Angora, some part of the circuit will be a 'Standard' carrier channel." As early as 1932, the International Standard Electric Corporation or its Licensee Companies had furnished carrier equipments as follows:[66]

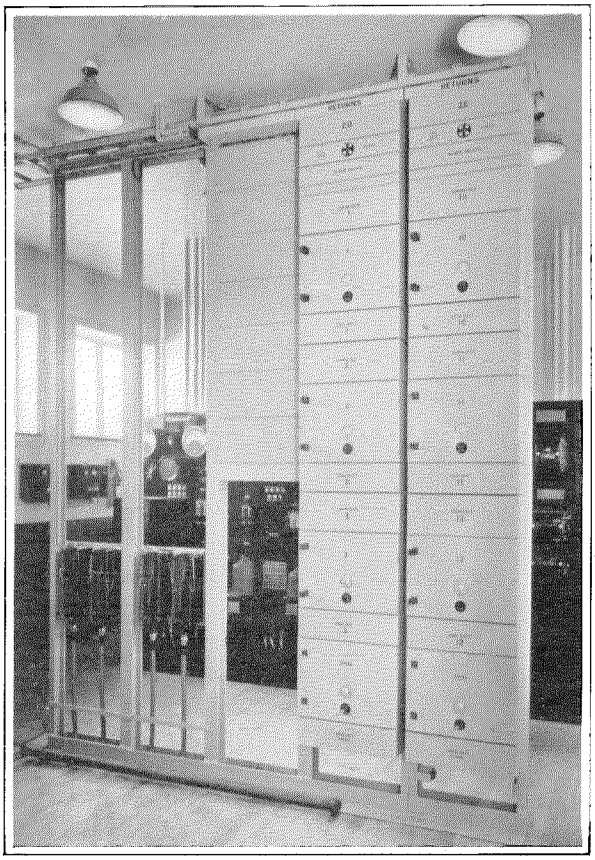
Country	Number	Country	Number
Argentina	44	Italy	14
Australia	165	Japan	41
Austria	2	Lithuania	2
Brazil	5	Malaya	17
Bulgaria	6	Mexico	4
Canada	55	Morocco	6
Ceylon	2	New Zealand	53
China	12	Norway	9
Cuba	8	Rhodesia	4
Czechoslovakia	7	Rumania	50
Finland	22	Russia	5
France	109	South Africa	23
Great Britain	30	Spain	74
Hungary	10	Sweden	94
Iceland	2	Turkey	3
India	10	Yugoslavia	6
Irish Free State	1		
			895

The latest data would be interesting but, because of disturbed world conditions, are not available.

The longest 3-channel system over open-wire lines ever undertaken was recorded by Standard Telephones and Cables, Ltd., London, in 1938 as in process of construction: the Russian system for the Moscow-Khabarovsk route—8,620 km in length. It included a broadcast program channel.[117]

BROAD BAND SYSTEMS

The British General Post Office for about the past five years has planned the extension of its network largely on the basis of modern multi-



Amplifier Equipment for Unattended Repeater Stations—Bristol-Plymouth 12-Channel Carrier System Type. Power supply equipment is in background; batteries are in separate room. Equipment shown provides for 6 twelve channel systems (both directions).

channel carrier technique. An outstanding example is the Bristol-Plymouth 12-channel carrier system,[69] providing 12 channels per pair in the 12 to 60 kc range with separate cables for the two transmission directions. The system was designed, when fully equipped, to provide 228 circuits.

At the end of the year 1938, incidentally, over 3,760 km of 12-channel cable were completed or under construction in Great Britain, representing a route length of 1,880 km.[118] During 1939 (the latest figures available) 900 km of 12-channel cable were installed; 1,100 km were under construction or on order.[119]

Taking future television development into account, the G.P.O. pioneered in the installation of coaxial cables. Additions to the telephone network in Great Britain during 1937 included an extension of the London-Birmingham coaxial cable, i.e., the Birmingham-Manchester-Leeds-Newcastle coaxial systems for telephony and television. At the end of 1937, 350 km route length of such cable was under construction (containing four coaxial cores).[70] It is interesting to note that the London-Birmingham coaxial cable employed Cotopa as an insulating material in order to achieve low high frequency loss and phase angle, etc.[140]

Australia installed the first open wire type J Carrier Telephone System outside of the U. S. A. on the Sydney-Melbourne route. It provides 12 channels on a single pair in addition to 3 channels already derived from a type C system and the normal voice frequency circuit, yielding a total capacity of a pair thus equipped of 16 circuits.[121] A second similar system on this route is planned for installation late in 1942.

In 1940, the latest link in the Swedish toll cable system was completed by joining the two cities of Göteborg and Malmö, a distance of 277 km, by a 12-channel carrier cable system.[122] In Finland, a similar installation recently was completed.

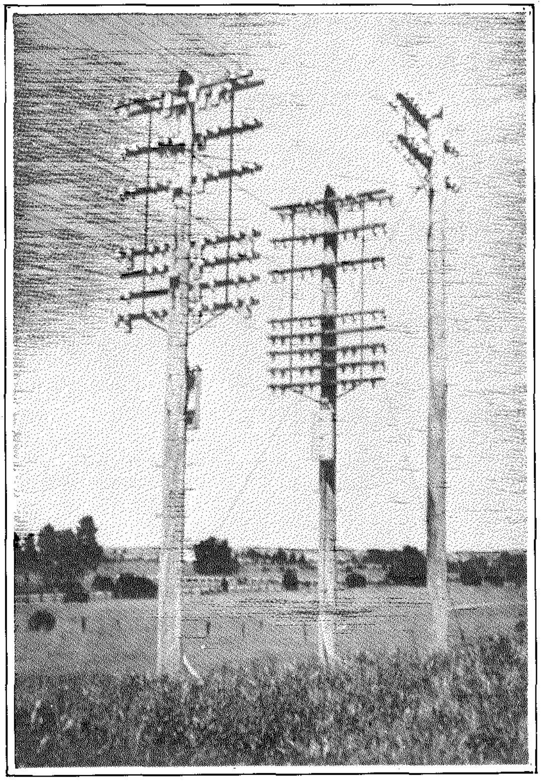
FUNDAMENTAL TRANSMISSION PLANNING OF TELEPHONE NETWORKS

Following a series of C.C.I.F. recommendations entitled, "Guiding Principles for the General European Switching Plan," a series of two articles considered local and toll area planning to meet the C.C.I.F. recommendations.[123] Part I dealt with the general transmission problem imposed by these recommendations, consideration being given to maximum permissible transmitting and receiving losses in the national systems if the agreed overall limits for an international connection were to be met. Part II discussed some of the practical steps necessary in coordinating national design so as to meet the international limits.

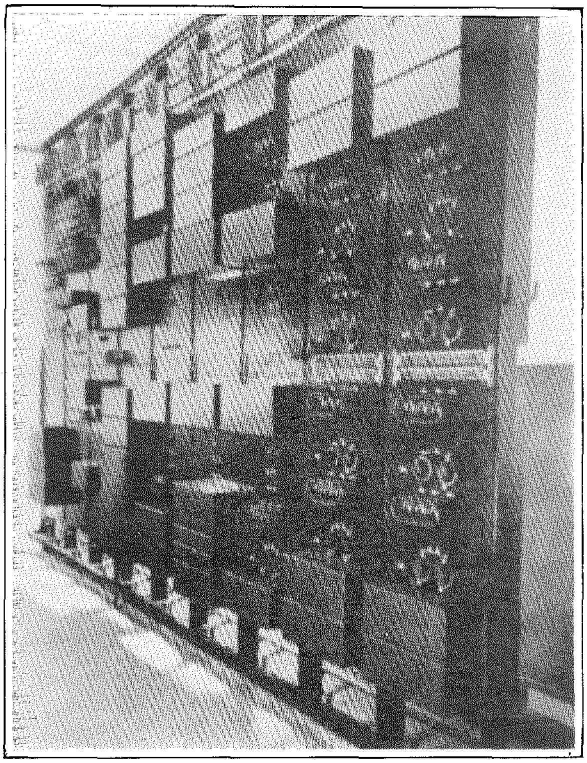
On occasions too great to enumerate, this journal has published articles relating to the development and coordination of European national and international networks, commencing with Sir Frank Gill's above cited suggestions which led to the formation of the C.C.I. Members of the I. T. & T. and associate companies frequently have been in a position to make constructive suggestions to the C.C.I. (the C.C.I.F., C.C.I.T. and C.C.I.R.) as a result of broad experience: through research, development and manufacture in different countries; the supply of communication equipment throughout the world; development and operation of telephone properties on four continents; operation of radio and land line systems linking four continents telephonically; and operation of telegraphic radio links and submarine cable systems on a world-wide basis.

SUBMARINE CABLE SYSTEMS

Along with the provision in 1929 of the above-mentioned Spanish-South American radiotelephone link, a radio link between Spain and the Canary Islands was established with a submarine cable interconnecting the islands of Tenerife and Gran Canaria. In addition, a submarine cable was laid between Algeciras, Spain, and Ceuta, Spanish Morocco. These multi-channel carrier telephone cables were of a special type, the core of which was insulated with gutta percha surrounded with copper wires serving as a sea-return conductor. In addition to the special type of core, an important factor was the improvement in the method adopted for the allocation of the core lengths to obtain smooth impedance distribution, whereby a singing point of 50 db was attained up to a 30 kc frequency. Further, the scheme of measuring attenuation was such that tests were conducted up to 50 db by the "open and short" method.[124]



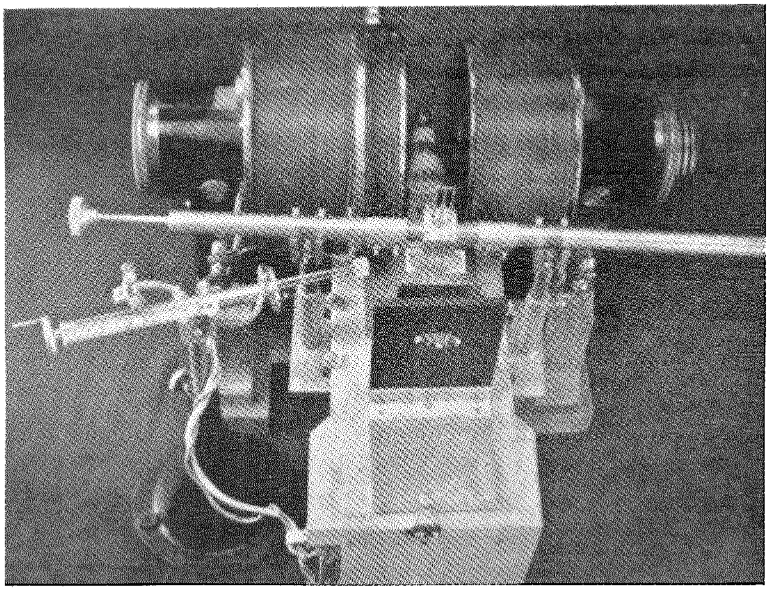
Sydney-Melbourne 12-Channel Carrier Telephone System. Typical Y-Pole Arrangement.



Cable Equipment, Stanley-New Bass Strait Submarine Cable System.

The world's two longest submarine telephone cables were described in this journal: (*a*) the Italy-Sardinia Cable[125] (146 nautical miles); and (*b*) the cable system between the Australian mainland and the island State of Tasmania[126] (160.97 nautical miles) consisting of two sections with a repeater station at King Island.

The latter project (known as the Bass Strait Submarine Cable System) employs a single non-loaded central conductor with coaxial return. The system represented the first case in which reversed feedback amplifiers were used in a submarine cable. In addition to being longer, the cable system is operated with frequencies higher than any other submarine cable telephone system. The following table shows the terminating



Magnetron. Showing the Generator of Oscillation at a Wavelength of 2.5 cm (In Air) and Its Associated Wave Meter; Also, the Method of Coupling to a Dielectric Guide 1.6 cm Internal Diameter.

points for the various circuits required initially and also for those to be provided subsequently:

	Type of Com. Channel	Melbourne-Launceston	Melbourne-Hobart	Total
Initial Installation	Duplex Teleph.	3	—	3
	Duplex Teleg.	3	2	5
	Broadcast Program (reversible channel)	—	1	1
Later Additional Installation	Duplex Teleph.	—	2	2
	Duplex Teleg.	1	1	2

The system was designed and the equipment manufactured by Standard Telephones and Cables, Ltd., London. The cable was manufactured and laid by Siemen Bros. & Co., Ltd.

DIELECTRIC (CYLINDRICAL) GUIDES

International Telephone Laboratories for over ten years have concentrated attention on ultra-high frequency technique, not only in the radio field, such as micro-ray transmission systems with concentrated beams working on 1600 mc, but also in connection with dielectric (cylindrical) guides, coaxial cables, etc. Theoretical relationships, transmission irregularities of various types of waves and their effect on communications and television, as well as ultra-high frequency wave characteristics, have been studied.[26 to 35 incl.]

Printing Telegraphy

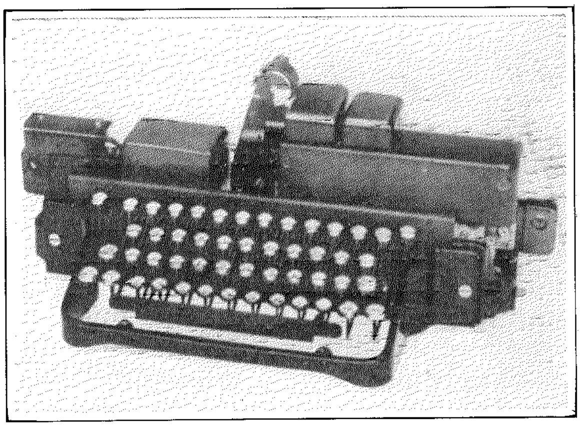
To meet the requirements of telegraph exchange service, Creed & Co., Ltd., London, designed a modified teleprinter arranged on a unit basis so that, in the event of trouble, any unit of the machine could readily be replaced in the field. In general, the principle of operation of earlier type machines was retained, but in the machine developed for teleprinter exchange service a special device was incorporated for transmitting back to the calling subscriber the exchange and number of the called subscriber, thus verifying the correctness of the connection.[127]

The introduction of Teleprinter Systems accelerated service, reduced costs and influenced telegraph practice markedly. On the other hand, experience in the field focused attention on the desirability of providing teleprinters with a keyboard conforming strictly to that of the commercial typewriters. This at one time was considered impracticable as it appeared to necessitate the introduction of a six unit code, thus precluding intercommunication with existing systems.

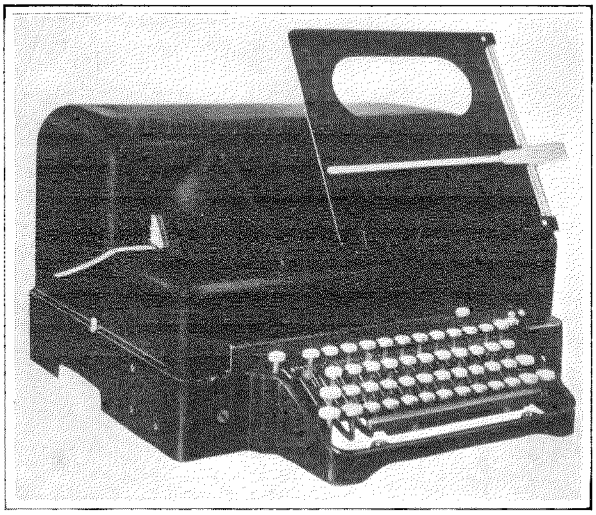
Creed & Co. solved this problem by retaining the established five unit code but arranging for the automatic insertion of a shift signal whenever the sending of a figure or punctuation mark was required. To transmit this additional signal without slowing down operation, a storage device was provided, holding the permutations corresponding to the key last depressed until the appropriate shift signal had been transmitted automatically. This cleared the way for a keyboard conforming strictly to the commercial typewriter layout.[128]

Progress initiated by the introduction of Teleprinter Systems requiring no telegraphic skill on the part of operators altered the whole outlook of telegraphy and stimulated development in all its branches. "All the older types of machines are rapidly being superseded by Teleprinters (1938); and even hand Morse working—the backbone of telegraphy for more than a century—has now been abandoned by the British Telegraph service, the bulk of the traffic being handled by Creed Teleprinters." With parallel developments in other countries, a "New Telegraphy" was evolved. To meet modern requirements, the Creed No. 10 Tape Teleprinter was introduced.

The No. 10 Teleprinter[129] is radically different in design from other Creed Teleprinter Systems and incorporates mechanisms entirely new in the printing telegraph art. It employs the principle of aggregate motion, the difficulties encountered by earlier telegraph inventors in engineering this simple and positive method of controlling a typewheel being overcome by evolving a novel patented system of epicyclic gearwheels operated by means of ratchet clutches so as to impart harmonic motion to the individual gear wheels and the typewheel. Hence, comparatively noiseless operation is achieved. Further, this Teleprinter is capable of operating at higher speeds than existing types and provides more economical maintenance.



Creed Teleprinter with Keyboard Conforming Strictly to the Commercial Typewriter Layout.



Combined Sending and Receiving Creed 10-B Teleprinter.

In 1932, an ingenious method was described for the electrical conversion of the non-uniform length combinations of the cable (Morse) Code into a modified five unit code.[130] This method solved the problem of direct printing over long non-loaded submarine telegraph cables and has been applied successfully in the Commercial Cable and All America cable systems.

The Commercial Cable and All America cable systems generally employ an automatic printer operated directly from 3-element cable code signals. By means of specially devised translators the 3-element signals may be translated into 2-element signals for transmission over ordinary landline telegraph plant; conversely, the 2-element signals may be restored to their 3-element form and, also, they may be monitored without retranslation. Synchronism between translators and retranslators is not required.[131]

TELEPRINTER SWITCHING SYSTEMS

Due to limitations of now obsolete telegraph instruments, telegraph exchanges fell into disuse, but, with the advent of the modern Teleprinter, capable of being operated by regular office employees without any considerable special training, they again were viewed more favorably. Developments in Teleprinter Switching Systems were described in 1938, including general switching principles, automatic and manual switching, substation equipment and broadcasting arrangements.[132]

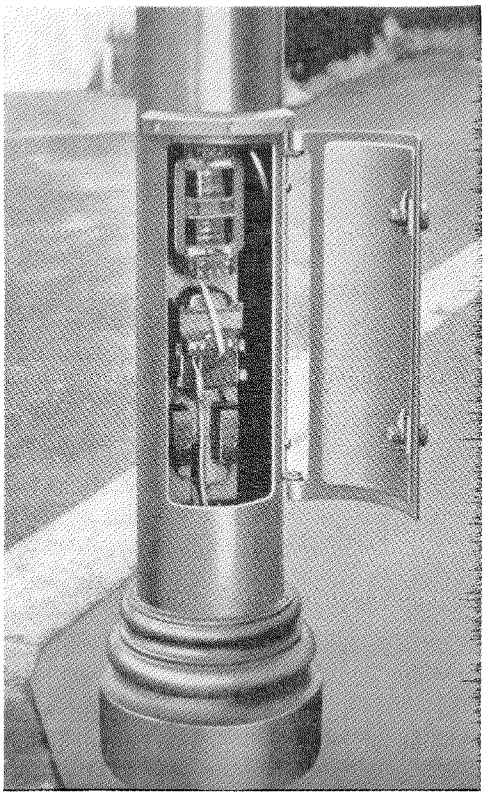
Supervisory Remote Control

In recent years supervisory control equipment has found increasing application, such as in railway and traction systems, involving the remote control of substations through which the high tension supply is ultimately fed to the track or trolley wire systems. Plans for development of railway electrification schemes in England and, more particularly in the environs of London, lent special interest to two such installations on suburban railway systems for the supervisory control of unattended substations, i.e., those of the London, Midland and Scottish Railway Company and the London Underground Railways.

The operating fundamentals and range of facilities generally are similar in both installations, which embody the principles of the Constant Total Code System.[133, 134] Facilities provided by the L.M.S. Railway installation include:

(*a*) Control and indication of:
  (1) 13 Rotary Converters
  (2) 5 Mercury Arc Rectifiers
  (3) 17 E.H.T. Feeder Breakers
  (4) 25 Track Feeder Breakers
  (5) 2 Protection Circuits.
(*b*) Control of Mass Firing of 12 Track Feeder Breakers in pairs at adjacent sub-stations.
(*c*) Indication of:
  (1) 13 E.H.T. Breakers
  (2) 2 Rotary Converters
  (3) 4 Track Feeder Breakers
  (4) 2 Tunnel Trip Circuits.
(*d*) Selection of any of 19 readings of d-c volts and amperes.
(*e*) Constant proving of line continuity.
(*f*) Means for switching control and substation equipment to or from spare line.
(*g*) Indication of remote and local fuse alarms.
(*h*) Routine testing access equipment with portable test sets.

Standard Telephones and Cables, Ltd., London, in the early nineteen-thirties gave attention to the problem of remote control of street lighting; and, after considering expensive schemes depending on the utilization of high frequency alternating current, concluded that a considerably cheaper method might be adopted, involving the application of a d-c bias to the network. With the development of a ready means of separating the a-c from the d-c at the receiving lamp post, the S.T.C. Direct Current Bias System was evolved.[135] The system has the very great advantage that it can be applied in the first instance locally to particular districts of a network and, as other methods or equipment in use elsewhere become due for replacement, it can be extended until the whole of the street lighting of a town is controlled from one point. The system



Remote Control over Power Mains of Street Lighting, Water Heating and Other Services. Lighting unit mounted in base of street post.

is low in initial cost, thoroughly reliable, and simple and robust in design.

The City of Lichfield (England) was one of the first to adopt this d-c bias system for the control of street lighting and other services. On the night of March 8, 1938, the City Engineer, with the cooperation of the authorities gave a demonstration of the use of the system for the control of street lighting, the operation of air raid alarms, and the calling out of volunteer firemen and air raid wardens to some two hundred engineers from all parts of Great Britain.

The application of telephone technique and telephone type apparatus has been greatly extended in the control circuits of heavy electrical equipment. An example is an order received by S.T.C. for the supply of remote control, indication and telemetering equipment for ten substations on the new extension of the London Passenger Transport Board's underground railway from Highgate over the London & North Eastern Railway Company's lines to High Barnet and Edgware.[136]

Esterified Fibrous Insulating Materials

In January, 1935, the first of a series of articles on the above subject was published in this journal; it cited a new material, Cotopa, as an example of fibrous materials especially produced for electrical engineering purposes by modifying their chemical structure. Its outstanding value was shown to be its high insulation resistance—superior to cellulose acetate silk, the best textile insulator previously known. It is comparable with cotton in mechanical strength and running properties in machines. In these characteristics and in its higher decomposition temperature, Cotopa is much superior to acetate silk, and is immune from attacks by fungi or mildew.[137]

Following the general survey of the application of fibrous materials to electrical insulation and of the improvement from an electrical viewpoint produced in cellulosic materials by acetylation (Part I), the practical details of manufacture, application and testing of these acetylated cellulosic fibrous materials was treated more fully. A short dissertation of modern ideas on the structure of cellulosic materials was added (Part II).[138]

Previous indication that a new technique of insulating materials was appearing on the horizon and that the insulation of the future will be prepared synthetically or will be chemically processed to eliminate inherent natural defects was illustrated in Part III:[139] (1) improvement of processing of acetylated cotton to a stage providing insulation ten to twenty times superior to any insulation previously known; (2) development of processes for the analogous treatment of natural silk and wool to meet the demand for high grade insulation with fireproof characteristics superior to those obtainable from cellulosic materials.

Recent developments in and the properties of various fibrous insulants including acetylated paper were discussed in 1940.[140]

High Tension Developments

Standard Telephones and Cables, Ltd., London, for the past 15 years has been active in the power field, both in its development and manufacturing aspects. In order to insure the production of high quality power cables, the problem of adequate testing has been continuously studied.[141] Notable developments are the Condenser Cone and Styrene.

In the high power cable field, terminations and joints are of prime importance. For these applications, the Condenser Cone[142] effected a startling improvement in the ability of cable ends to withstand high voltages. It is cheap to construct, easy to install, and its range of application is wide.

In 1937, 1938 and 1940 a notable series of articles was published on the utilization of styrene in high tension cable systems.[143] Since 1938 much research has been undertaken to extend styrenation technique in the light of experience gained under service conditions, and new methods of making styrene joints, plugs and terminations have been evolved. Simplification and cost reduction have been carried to the stage where general use can be made of barrier action in cables. Bonded styrenated paper also has been introduced as a product likely to have widespread commercial application.

The International Telephone & Radio Manufacturing Corporation, as a result of development progress in the power cable field in connection with joints and terminations, is preparing for the manufacture of styrenated papers, styrene rubber, etc. It is felt that in the near future styrene, not only in the H.T. insulation field, but also in

Symbol of Neighborliness in South America. At the feet of Christ of the Andes, I. T. & T. engineers and installers burying the transcontinental cable interconnecting Argentina and Chile.

the high frequency insulation field, is likely to become more universal.[145]

Conclusion

In concluding this survey of the past twenty years, it is fitting to give grateful recognition to Pioneers of Electrical Communication who laid the foundation for the astounding achievements of our age in electrical communications. A series of biographical articles, embodying considerable original material, was published in *Electrical Communication* in the years 1926–1929. The pioneers included were: James Clerk Maxwell, André Marie Ampère, Alessandro Volta, Charles Wheatstone, Heinrich Rudolph Hertz, Hans Christian Oersted, Georg Simon Ohm, Oliver Heaviside, and Claude Chappe. Recently an article on Peder Oluf Pedersen appeared.[146 to 155 incl.]

Because of the size of this review, much material has been omitted or mentioned only incidentally. The Selenium Rectifier, on which articles have recently been included in this journal, [157, 158] and numerous descriptions of activities of I.T. & T. Associate operating telephone, telegraph and radio companies are cases in point. One article—too lengthy for summarization—is deserving of special emphasis: "Operations of the International Telephone and Telegraph Group of Companies in the Americas."[72] It shows quite clearly the contributions which the I.T. & T. Corporation and its Associate Companies have made to Western Hemisphere communications, particularly in South America.

An exemplification of these contributions is afforded by the following quotation from *Electrical Communication* referring to Western Hemisphere Broadcast Networks, President Roosevelt's Fireside Chat of May 27, 1941:[156]

"Wide dissemination of programs of this character thus can be effected only through local medium wave broadcast stations to which every radio set owner is a potential listener. For adequate national or international hookups, furthermore, local stations must be served by high quality wire networks or radiotelephone circuits (inter-linked radio stations). It is, accordingly, a happy circumstance that the International Telephone and Telegraph Corporation, primarily due to its activities in developing local, national and international communications in the Southern continent, has at its disposal both wire networks and national and international radiotelephone stations for providing program transmission service to the broadcast stations in many of the important countries in the Western Hemisphere."

* * *

"Reports confirmed the excellent transmission quality and the interest evoked by the address. The South American network, giving coverage to an estimated ten million listeners, was the most comprehensive ever established on that continent for a single program originating in the U. S. A."

An indication of the world-wide scope of the contributions recorded in *Electrical Communication* may, perhaps, best be gleaned by recalling The Coronation of Their Majesties King George VI and Queen Elizabeth in London on May 12, 1937. In broadcasting the Coronation Ceremony from Westminster Abbey, Standard Electric types of equipment included:[83]

"The microphones used for picking up the Abbey service and the cheers of the vast crowds; four of the B.B.C. Empire broadcast transmitters (two of these were the new high power stations, the installation of which was specially expedited for this purpose, and two were older, lower power stations); the international telephone exchange toll test racks through which all the telephone circuits were set up; the radio transmitters used on several of the radiotelephone circuits; radiotelephone and switching facilities in Argentina, Brazil and other countries; and radiotelephone equipment in hundreds of ships including liners such as the Cunard White Star *Queen Mary* and *Berengaria*. The wire telephone circuits to the 13 European countries included much Standard type apparatus in the form of Cable, Loading Coils, Repeaters, Carrier Equipment, Toll Switchboards, etc. . . . Standard type broadcasters in numerous countries were involved in retransmissions of the programs."

Modern war inevitably imposes requirements that press heavily even on the most comprehensive communication networks. Moreover, demand for the completion of fundamental research and development projects carried out in laboratories of private companies, often with a view to utilization in the longer future, suddenly becomes urgent. At present, this is especially true in the field of ultra-high frequency technique involving television, dielectric guides, sharply concentrated U.H.F. beams, etc. As may be inferred from citations in this report, the International Telephone and Telegraph Corporation and Associate Companies, fortunately, have for a period of over ten years devoted special attention to the ultra-high frequency field.

Communications, not infrequently, have played their part in events that have become historic; at times, in fact, such as in the telegraphic and telephonic interconnection of continents, they have made history. In time to come the communications art seems destined to play an even greater rôle in its service to mankind.

References

1. "The Future of Long Distance Telephony in Europe," by Frank Gill, *El. Com.*, Vol. 1, No. 2, 1922.
2. "European Long Distance Telephony," *El. Com.*, Vol. 2, No. 2, 1923.
3. "European International Telephony," by Frank Gill, *El. Com.*, Vol. 3, No. 1, 1924.
4. "European Telephony as Affected by the International Telephone Committee—C.C.I.," *El. Com.*, Vol. 6, No. 1, 1927.
5. "The Recent Transatlantic Radiotelephone Tests," *El. Com.*, Vol. 1, No. 3, 1923.
6. "Transatlantic Radiotelephone Transmission," by L. Epenschied, C. N. Anderson and A. Bailey, *El. Com.*, Vol. 4, No. 1, 1925.
7. "Transatlantic Radiotelephony—Radio Station of the British Post Office at Rugby," by E. M. Deloraine, *El. Com.*, Vol. 5, No. 1, 1926. See also "The Rugby Radio Station," by E. H. Shaughnessy, *El. Rev.*, April 30, 1926; May 7, 1926.

7a. "Transatlantic Telephony Between the Institution of Electrical Engineers, London, and the Institute of Electrical Engineers, New York," *El. Com.*, Vol. 6, No. 4, 1928.

8. "Madrid—Buenos Aires Radio Link and Its Wire Connections," by G. H. Gray and N. K. Fairbank, *El. Com.*, Vol. 8, No. 4, 1930.
9. "The Use of Short Waves in Radio Communication," by E. M. Deloraine, *El. Com.*, Vol. 8, No. 4, 1930.
10. "The 'Standard' Short Wave Radio Transmitters," by C. E. Strong, *El. Com.*, Vol. 8, No. 4, 1930.
11. "Short Wave Radio Telephone and Telegraph Receivers," by E. H. Ullrich and R. E. Gray, *El. Com.*, Vol. 8, No. 4, 1930.
12. "Thermionic Vacuum Tubes for Short Waves," by W. T. Gibson, *El. Com.*, Vol. 8, No. 4, 1930.
13. "Short Wave Directive Transmitting and Receiving Antennas," by E. H. Ullrich and N. K. Fairbank, *El. Com.*, Vol. 8, No. 4, 1930.
14. "Terminal Equipments for Short Wave Point-to-Point Radio Links," by F. de Fremery and P. R. Thomas, *El. Com.*, Vol. 8, No. 4, 1930.
15. "Inauguration of Madrid-Buenos Aires Radiotelephone Link," by F. T. Caldwell, *El. Com.*, Vol. 8, No. 4, 1930.
16. "The New York—Buenos Aires Radio Circuit," by H. H. Buttner, *El. Com.*, Vol. 8, No. 5, 1930.

16*a*. "The Spread (Displaced) Sideband System on Short Wave Telephone Links," by L. T. Hinton, *El. Com.*, Vol. 10, No. 2, 1931.

17. "The Single Sideband System Applied to Short Wavelengths," by A. H. Reeves, *El. Com.*, Vol. 10, No. 1, 1931.
18. "Micro-Ray Radio," *El. Com.*, Vol. 10, No. 1, 1931.
19. "Production and Utilization of Micro-Rays," by A. G. Clavier, *El. Com.*, Vol. 12, No. 1, 1933.
20. "The Anglo-French Micro-Ray Link Between Lympne and St. Inglevert," by A. G. Clavier and L. C. Gallant, *El. Com.*, Vol. 12, No. 3, 1934.
21. "Micro-Ray Communication," by W. L. McPherson and E. H. Ullrich, *El. Com.*, Vol. 14, No. 4, 1936.
22. "Propagation Tests with Micro-Rays," by A. G. Clavier, *El. Com.*, Vol. 15, No. 3, 1937.
23. "Superheterodyne Reception of Micro-Rays," by A. H. Reeves and E. H. Ullrich, *El. Com.*, Vol. 16, No. 2, 1937.
24. "Ultra-Short Wave Communication," by E. H. Ullrich, *El. Com.*, Vol. 16, No. 1, 1937. See also "Bellfast-Stranraer 9-Circuit Ultra-Short Wave Radiotelephone System—Part II," by D. B. Mirk, *P.O. Elec. Engrs. Jnl.*, pp. 33–40, April, 1938.
25. "The Eiffel Tower Television Transmitter," by S. Mallein and G. Rabuteau, *El. Com.*, Vol. 17, No. 4, 1939.
26. "Some Problems of Hyperfrequency Technique," by A. G. Clavier and E. Rostas, *El. Com.*, Vol. 16, No. 3, 1938.
27. "Theoretical Study of Dielectric Cables," by L. Brillouin, *El. Com.*, Vol. 16, No. 4, 1938.
28. "General Properties of Dielectric Guides," by J. Saphores, *El. Com.*, Vol. 16, No. 4, 1938.
29. "Theoretical Relationships of Dielectric Guides (Cylindrical) and Coaxial Cables," by A. G. Clavier, *El. Com.*, Vol. 17, No. 3, 1939.
30. "Experimental Researches on the Propagation of Electromagnetic Waves in Dielectric (Cylindrical) Guides," by A. G. Clavier and V. Altovsky, *El. Com.*, Vol. 18, No. 1, 1939.
31. "Hyperfrequency Waves and Their Practical Use," by L. Brillouin, *El. Com.*, Vol. 19, No. 4, 1941.
32. "Electromagnetic Waves in Metal Tubes of Rectangular Cross-Section," by J. Kemp, *El. Com.*, Vol. 20, No. 2, 1941.
33. "Theory of the Magnetron," by L. Brillouin, *El. Com.*, Vol. 20, No. 2, 1941.
34. "Irregularities in Telephone and Television Coaxial Cables," by L. Brillouin, *El. Com.*, Vol. 17, No. 2, 1938.
35. "Notes on the Effects of Irregularities in Coaxial Cables on Television Transmission," by J. Saphores and P. Gloess, *El. Com.*, Vol. 17, No. 2, 1938.
36. "The Prague High Power Broadcasting Equipment," by D. B. Mirk, *El. Com.*, Vol. 10, No. 3, 1932.
37. "'Standard' High Power Broadcasting Transmitters at Budapest and Kalundborg," by C. E. Strong, *El. Com.*, Vol. 12, No. 4, 1934.
38. "The Budapest Anti-Fading Antenna," by F. Holland, C. E. Strong and F. C. McLean, *El. Com.*, Vol. 12, No. 4, 1934.
39. *El. Com.*, Vol. 16, No. 3, p. 189, 1938.
40. "Ship-and-Shore Terminal Equipment," by A. S. Angwin, *El. Com.*, Vol. 9, No. 1, 1930.
41. "Mobile Radiotelephony," by F. G. Loring and H. H. Buttner, *El. Com.*, Vol. 11, No. 2, 1932.
42. "The Automatic Radio Compass and Its Applications to Aerial Navigation," by H. Busignies, *El. Com.*, Vol. 15, No. 2, 1936.
43. "Reduction of Night Error in Radio Direction Finding Equipment for Aerodromes," by H. Busignies, *El. Com.*, Vol. 16, No. 3, 1938; also, "Control of Night Error in Airplane Direction Finding," by H. Busignies. (A paper presented at the I.R.E. Summer Convention, Detroit, June 23, 24 and 25, 1941.)
44. "Mountain Effects and the Use of Radio Compasses and Radio Beacons for Piloting Aircraft," by H. Busignies, *El. Com.*, Vol. 19, No. 3, 1941.
45. "Development of the C.A.A. Instrument Landing System at Indianapolis," by W. E. Jackson, A. Alford, P. F. Byrne, and H. B. Fischer, *El. Com.*, Vol. 18, No. 4, 1940; *El. Com.*, Vol. 19, No. 3, p. 5, 1941.
46. "Airport Communications," by R. H. Riddle, *El. Com.*, Vol. 20, No. 1, 1941.
47. "High Frequency Transmission Line Networks," by Andrew Alford, *El. Com.*, Vol. 17, No. 3, 1939.
48. "Ultra-High Frequency Loop Antennae," by A. Alford and A. G. Kandoian, *El. Com.*, Vol. 18, No. 4, 1940.
49. "The Rotary Automatic Telephone Introduced Into Paris," by G. Deakin, *El. Com.*, Vol. 7, No. 2, 1928.
50. "Trunking Plans of the Paris Network," by S. V. C. Scruby, *El. Com.*, Vol. 13, No. 2, 1934. See also *Annales Des Postes Télégraphes et Téléphones:* "Transformation en Automatique de la Région de Paris," by André Duprez, June, 1938; "Adaptation du Réseau Téléphonique de Paris à L'Exploitation

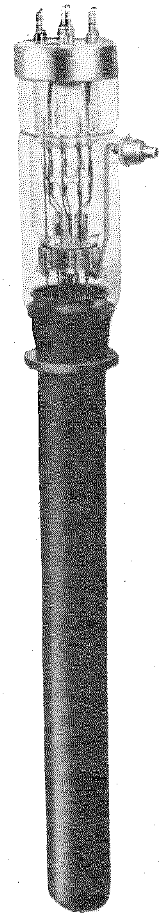
Automatique de la Région de Paris," by André Blanchard, July, 1938.

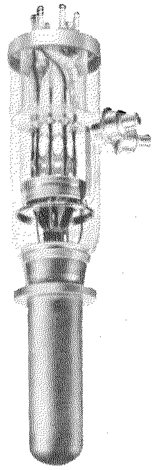
51. "A Rural Rotary Automatic Telephone System Installed at Herrliberg," by W. Hatton, *El. Com.*, Vol. 8, No. 1, 1929.
52. "Automatic Telephony in the Zurich Area," by E. Wollner, *El. Com.*, Vol. 8, No. 2, 1929.
53. "Rotary Automatic in Switzerland," by G. Deakin, *El. Com.*, Vol. 9, No. 3, 1931.
54. "Automatic Long Distance Switching and National Dialing—Basle, Switzerland," by E. Frey, *El. Com.*, Vol. 12, No. 4, 1934.
55. "National Dialing in the Netherlands," by J. P. Verlooy and M. Den Hertog, *El. Com.*, Vol. 17, No. 1, 1938.
56. "A Field Trial of 50 Cycle Signaling on Toll Lines," by W. Hatton, *El. Com.*, Vol. 15, No. 2, 1936.
57. "Development Aspects of International Voice Frequency Signaling and Dialing Under Consideration by the C.C.I.F.," by E. P. G. Wright, *El. Com.*, Vol. 18, No. 1, 1939.
58. "7A-2 Rotary Automatic Telephone System—Part I," by L. Schreiber and W. Hatton, *El. Com.*, Vol. 11, No. 4, 1933.
59. "7A-2 Rotary Automatic Telephone System—Part II," by L. Schreiber and W. Hatton, *El. Com.*, Vol. 12, No. 1, 1933.
60. "7A-2 Rotary Automatic Telephone System—Part III," by L. Schreiber and W. Hatton, *El. Com.*, Vol. 12, No. 2, 1933.
61. "7D Rotary Automatic Telephone System," by W. Hatton and J. Kruithof, *El. Com.*, Vol. 13, No. 4, 1935.
62. "Automatic Ticketing of Telephone Toll Calls," by Leslie B. Haigh, *El. Com.*, Vol. 15, No. 4, 1937.
63. "Automatic Printing Register for Telephone Call Recording," by L. Devaux, *El. Com.*, Vol. 15, No. 4, 1937.
64. "The Application of Automatic Ticketing to Step-By-Step Systems," by E. P. G. Wright, *El. Com.*, Vol. 17, No. 3, 1939.
65. "Automatic Ticketing of Long Distance Telephone Connections," by W. Hatton, *El. Com.*, Vol. 18, No. 3, 1940.
66. "Carrier Current Systems Form Important Part of World Communication Network," by J. S. Jammer, *El. Com.*, Vol. 11, No. 2, 1932.
67. "Australia First to Use Type C-2-F Carrier System," by J. S. Jammer, *El. Com.*, Vol. 7, No. 1, 1928.
68. "Paris-Strasbourg Cable," *El. Com.*, Vol. 6, No. 1, 1927.
69. "Bristol-Plymouth 12-Channel Carrier System, *El. Com.*, Vol. 16, No. 2, 1937.
70. *El. Com.*, Vol. 16, No. 3, p. 186, 1938. See also "Modern Systems of Multi-Channel Telephony on Cables," by A. S. Angwin and R. A. Mack, *Jnl. of the I.E.E.*, Nov., 1937.
71. "Recent Developments in Electrical Communication," by J. L. McQuarrie, *El. Com.*, Vol. 1, No. 1, 1922.
72. "Operations of the International Telephone and Telegraph Group of Companies in the Americas," by W. F. Repp, *El. Com.*, Vol. 19, No. 3, 1941.
73. "The Single Sideband System Applied to Short Wave Telephone Links (Summary)," by A. H. Reeves, *El. Com.*, Vol. 12, No. 2, 1933. For complete paper, see *Jnl. of the I.E.E.*, Sept., 1933; also "La Transmission Radiotéléphonique à Ondes Courtes, à Bande Latérale Unique et Autres Systèmes," by E. M. Deloraine, *Bull. de la Soc. Française des Electriciens*, p. 940, Aug., 1932.
74. "The Birmingham Broadcasting Station," by A. E. Thompson, *El. Com.*, Vol. 2, No. 3, 1924.
75. "Broadcasting in South Africa," by F. H. Amis, *El. Com.*, Vol. 3, No. 3, 1925.
76. "Broadcasting in Sweden, Norway and Denmark," by A. Taranger, *El. Com.*, Vol. 7, No. 1, 1928.
77. "Iceland and Its First Broadcasting Station," by K. H. Thow, *El. Com.*, Vol. 5, No. 4, 1927.
78. "The New Swiss Broadcasting Station," by F. C. McLean, *El. Com.*, Vol. 11, No. 1, 1932.
79. "The Swiss Broadcast Network," by A. Muri, *El. Com.*, Vol. 11, No. 1, 1932.
80. "Extension of Sottens Broadcasting Station to 100 KW," by E. Metzler, C. E. Strong, and F. C. McLean, *El. Com.*, Vol. 15, No. 1, 1936.
81. "British Empire Broadcasting," by C. M. Benham and P. H. Spagnoletti, *El. Com.*, Vol. 12, No. 4, 1934.
82. "British Broadcasting Corporation's Start Point Transmitter," *El. Com.*, Vol. 18, No. 1, p. 105, 1939.
83. "The Coronation," by F. Gill, *El. Com.*, Vol. 16, No. 1, 1937.
84. "Columbia Broadcasting System's New 50 KW Broadcasting Station WABC," *El. Com.*, Vol. 20, No. 2, p. 140, 1941.
85. "Final Stage Class "B" Modulation," by C. E. Strong, *El. Com.*, Vol. 16, No. 4, 1938.
86. "A New 120 KW Vacuum Tube," by W. T. Gibson and G. Rabuteau, *El. Com.*, Vol. 12, No. 2, 1933.
87. "Hot Cathode Mercury Vapour High Tension Supply Equipment for Broadcasting Stations," by G. Rabuteau, *El. Com.*, Vol. 15, No. 2, 1936.
88. *El. Com.*, Vol. 17, No. 3, p. 213, 1939.
89. "The Radio Installation on the Cunard White Star, R.M.S. Queen Mary," by H. Thorpe-Woods, H. H. Buttner, and E. N. Wendell, *El. Com.*, Vol. 15, No. 1, 1936.
90. "The Cunard White Star R.M.S. 'Queen Mary' Radio Installation," by F. G. Loring, W. L. McPherson, and W. H. McAllister, *El. Com.*, Vol. 15, No. 4, 1937.
91. "Q. S. T. S. 'Queen Elizabeth'" (Illustration), *El. Com.*, Vol. 17, No. 2, p. 100, 1938.
92. "A New Marine Radio Unit for Cargo Vessels," by E. J. Girard, *El. Com.*, Vol. 20, No. 2, 1941.
93. "Illumination of Presidente Rivadavia (Moron) Airport (Province of Buenos Aires)," by P. B. Padilla and E. T. G. Palmer, *El. Com.*, Vol. 19, No. 4, 1941.
94. "The Public Address System in Liverpool Cathedral," by A. F. Rickard, *El. Com.*, Vol. 5, No. 2, 1926.
95. "Vast Public Address System at 31st International Eucharistic Congress, Dublin, June, 1932," by W. L. McPherson, *El. Com.*, Vol. 11, No. 4, 1933.

96. "The Public Address System and Corollary Installations for the 32d International Eucharistic Congress," by R. T. Mulleady and W. White; see also "Transmitting The Program of the 32d International Eucharistic Congress," by K. McKim, *El. Com.*, Vol. 14, No. 1, 1935.
97. "Public Address System at the 34th International Eucharistic Congress," Budapest, May 22–29, 1938," by G. A. de Czeglédy, *El. Com.*, Vol. 17, No. 4, 1939.
97*a*. "The 1937 Paris Exhibition," by P. Quéffeléan, *El. Com.*, Vol. 16, No. 2, 1937.
98. "400 Line PABX-7055 Type," by M. A. Biske, *El. Com.*, Vol. 13, No. 3, 1935.
99. "Private Automatic Branch Exchanges," by W. Hatton and R. T. Ringkjob, *El. Com.*, Vol. 14, No. 3, 1936.
100. "No. 7D Rotary Automatic PBX Installed in the Administration Building of the Danish Newspaper 'Politiken'," by K. A. Haldvig, *El. Com.*, Vol. 16, No. 2, 1937.
101. "Airport PABX Network," by R. T. Ringkjob, *El. Com.*, Vol. 17, No. 3, 1939.
102. "Installation of the First Telephone Toll Cables in Japan," by R. P. Ashbaugh, *El. Com.*, Vol. 1, No. 3, 1923.
103. "The New Simplon Cable," by R. A. Mack, *El. Com.*, Vol. 1, No. 4, 1923.
104. "The Work of Installation of the Underground Telephone Cable—Milan—Turin—Genoa," by G. Maganini, *El. Com.*, Vol. 2, No. 3, 1924.
105. "The Italian State Toll Cable System," by G. di Perro, *El. Com.*, Vol. 9, No. 2, 1931.
106. "The Stockholm—Gothenburg Telephone Cable," *El. Com.*, by E. Ekeberg, Vol. 2, No. 4, 1924.
107. "The Stockholm—Norrköping Telephone Cable," by N. Hedén, *El. Com.*, Vol. 5, No. 1, 1926.
108. "Stockholm-Göteborg Railway Cable," by I. Billing, *El. Com.*, Vol. 4, No. 4, 1926.
109. "Stockholm-Malmö Railway Cable," *El. Com.*, Vol. 10, No. 2, 1931.
110. "The London-Glasgow Trunk Telephone Cable and Its Repeater Stations," by A. B. Hart, *El. Com.*, Vol. 5, No. 2, 1926.
111. "London Birmingham Loaded Cable," *P. O. Elec. Engrs. Jnl.*, Vol. 8, p. 206, 1915.
112. "The Danish Telegraph Administration's Toll Cable Network," by N. E. Holmblad, *El. Com.*, Vol. 14, No. 3, 1936.
113. "Hongkong-Canton Toll Telephone Cable," by P. T. Carey and R. E. Burnett, *El. Com.*, Vol. 10, No. 4, 1932.
114. "Czechoslovakian Cable System," by F. J. Stringer, W. F. Marriage and L. E. Pawley," *El. Com.*, Vol. 8, No. 3, 1930.
115. "Voice Frequency Carrier Telegraph System for Cables," by B. P. Hamilton, V. H. Nyquist, M. B. Long and W. A. Phelps, *El. Com.*, Vol. 3, No. 4, 1925.
116. "A New Voice Frequency Telegraph System," by J. A. H. Lloyd, W. N. Roseway, V. J. Terry and A. W. Montgomery, *El. Com.*, Vol. 10, No. 4, 1932.
117. *El. Com.*, Vol. 16, No. 3, p. 188, 1938.
118. *El. Com.*, Vol. 17, No. 3, p. 209, 1939.
119. *El. Com.*, Vol. 18, No. 3, p. 183, 1940.
121. "The Sydney-Melbourne Type J Carrier Telephone System," by J. T. O'Leary, J. B. Scott, and A. M. Thornton, *El. Com.*, Vol. 19, No. 1, 1940.
122. "12-Channel Carrier Equipment in the Göteborg-Malmö Cable," by S. R. Nordström, *El. Com.*, Vol. 20, No. 2, 1941.
123. "Fundamental Transmission Planning of Telephone Networks," by B. H. McCurdy, *El. Com.*, Part I: Vol. 18, No. 1, 1939; Part II: Vol. 19, No. 1, 1940.
124. "Tenerife-Gran Canaria and Algeciras-Ceuta Submarine Cables," by K. E. Latimer and J. R. Vezey, *El. Com.*, Vol. 9, No. 4, 1931.
125. "The New Italy-Sardinia Telephone Circuit," by A. G. Pession, *El. Com.*, Vol. 12, No. 2, 1933.
126. "The Carrier Telephone and Telegraph Equipment of the New Bass Strait Submarine Cable System," by F. Ralph and R. L. Hughes, *El. Com.*, Vol. 15, No. 4, 1937.
127. "Developments in Start-Stop Telegraphy—The New Creed Printer," *El. Com.*, Vol. 10, No. 2, 1931.
128. "Improved Teleprinter Keyboard Technique," by F. R. Thomas, *El. Com.*, Vol. 13, No. 1, 1934.
129. "The Creed No. 10 Tape Teleprinter," by A. E. Thompson, *El. Com.*, Vol. 16, No. 4, 1938.
130. "Direct Printing Over Long Non-Loaded Submarine Telegraph Cables," by M. H. Woodward and A. F. Connery, *El. Com.*, Vol. 10, No. 4, 1932.
131. "A Cable Code Translator System," by A. F. Connery, *El. Com.*, Vol. 14, No. 3, 1936.
132. "Some Recent Developments in Teleprinter Switching Systems," by P. F. Clemens, *El. Com.*, Vol. 16, No. 3, 1938.
133. "The Centralization of Control of Power Networks," by E. M. S. McWhirter, *El. Com.*, Vol. 13, No. 3, 1935.
134. "Supervisory Control of Traction Sub-Stations," by C. G. White, *El. Com.*, Vol. 16, No. 1, 1937.
135. "The Remote Control over Power Mains of Street Lighting, Water Heating and Other Services," by E. M. S. McWhirter, *El. Com.*, Vol. 17, No. 2, 1938.
136. "Remote Control of Power Stations," *El. Com.*, Vol. 17, No. 4, p. 399, 1939.
137. "Esterified Fibrous Insulating Materials—Part I," by A. A. New, *El. Com.*, Vol. 13, No. 3, 1935.
138. "Esterified Fibrous Insulating Materials—Part II," by A. A. New, *El. Com.*, Vol. 13, No. 4, 1935.
139. "Esterified Fibrous Insulating Materials—Part III," by A. A. New, *El. Com.*, Vol. 14, No. 3, 1936.
140. "Recent Developments in Esterified Fibrous Insulants," by A. A. New, *El. Com.*, Vol. 19, No. 2, 1940.
141. "A Modern High Voltage Cable Testing Plant," by T. N. Riley, *El. Com.*, Vol. 5, No. 4, 1927.
142. "The Condenser Cone," by J. K. Webb, *El. Com.*, Vol. 12, No. 2, 1933; "Condenser Cones for Cable

Testing," by J. K. Webb, *El. Com.*, Vol. 15, No. 4, 1937.

143. "The Application of Styrene to H. T. Cable Systems," by T. R. Scott and J. K. Webb, *El. Com.*, Part I: Vol. 16, No. 2, 1937; Part II: Vol. 16, No. 3, 1937; Part III: Vol. 17, No. 1, 1938; Part IV: Vol. 19, No. 2, 1940.
145. "Applications of Styrene to H. T. Cable Systems," *El. Com.*, Vol. 19, No. 4, p. 141, 1941.
146. "Pioneers of Electrical Communication—James Clerk Maxwell," by Rollo Appleyard, *El. Com.*, Vol. 5, No. 2, 1926.
147. "Pioneers of Electrical Communication—André Marie Ampère," by Rollo Appleyard, *El. Com.*, Vol. 5, No. 3, 1927.
148. "Pioneers of Electrical Communication—Alessandro Volta," by Rollo Appleyard, *El. Com.*, Vol. 5, No. 4, 1927.
149. "Pioneers of Electrical Communication—Charles Wheatstone," by Rollo Appleyard, *El. Com.*, Vol. 6, No. 1, 1927.
150. "Pioneers of Electrical Communication—Heinrich Rudolf Hertz," by Rollo Appleyard, *El. Com.*, Vol. 6, No. 2, 1927.
151. "Pioneers of Electrical Communication—Hans Christian Oersted," by Rollo Appleyard, *El. Com.*, Vol. 6, No. 4, 1928.
152. "Pioneers of Electrical Communication—George Simon Ohm," by Rollo Appleyard, *El. Com.*, Vol. 7, No. 1, 1928.
153. "Pioneers of Electrical Communication—Oliver Heaviside," by Rollo Appleyard, *El. Com.*, Vol. 7, No. 2, 1928.
154. "Pioneers of Electrical Communication—Claude Chappe," by Rollo Appleyard, *El. Com.*, Vol. 8, No. 2, 1929.
155. "Peder Oluf Pedersen," *El. Com.*, Vol. 20, No. 2, 1941.
156. "Western Hemisphere Broadcast Networks. President Roosevelt's Fireside Chat of May 27, 1941," by J. W. G. Ogilvie, *El. Com.*, Vol. 20, No. 1, 1941.
157. "Selenium Rectifier Characteristics, Application and Design Factors," by C. A. Clarke, *El. Com.*, Vol. 20, No. 1, 1941.
158. "Selenium Rectifiers for Closely Regulated Voltages," by J. E. Yarmack, *El. Com.*, Vol. 20, No. 2, 1941.
159. "Sir Frank Gill, K.C.M.G., O.B.E.," by F. K. Jewson, *El. Com.*, Vol. 20, No. 1, 1941.





F-124-A and F-898 Federal Telegraph Company Tubes

Above—The F-124-A Tube was developed to provide a power rating not previously available as well as increased efficiency and reserve power in broadcast and high frequency telegraph transmitters. It has a rated plate dissipation of 40 kw and a 5½ kw filament which may be connected to a single, 3 or 6 phase power source, giving total emission of 35 amperes. A double grid lead facilitates neutralization at high frequencies. Unique construction features permit relatively small physical dimensions in relation to power capabilities. Overall height: 25 inches.

Left—The F-898 Tube embodies a unique filament stem arrangement permitting sturdy overall construction. It is rated at 100 kw and was developed by Federal Telegraph to fit into existing, widely used equipment. Overall height: 60 inches.

Operating Results on the New Buenos Aires–New York Twin Channel Single Sideband Short Wave Radiotelephone Link

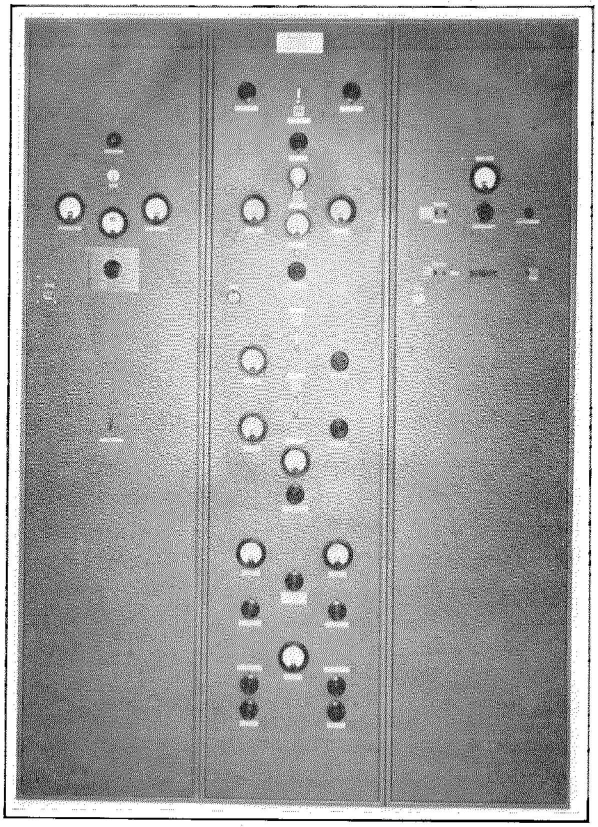
By A. M. STEVENS, A. B., FELLOW I. R. E.
General Manager, Compañía Internacional de Radio (Argentina), Buenos Aires

In December, 1940, Compañía Internacional de Radio (Argentina), CIDRA, an I. T. & T. subsidiary, installed a twin channel single sideband short wave equipment at its station near Buenos Aires. The results of the first year of operation have been highly gratifying from the viewpoint of improved transmission, and in addition, very substantial economies have been effected in tube replacements and power consumption. The latter is especially important under prevailing disturbed conditions inasmuch as it is necessary for Argentina to import its coal, resulting in a steady rise in power cost.

With a total a-c input of 5 kw, the new single sideband transmitter provides two good commercial channels, whereas the single channel double sideband unit formerly in service required 100 kw at full load. Thus, double the circuit capacity is obtained with 1/20th of the input power. Saving in replacement costs of vacuum tubes in the transmitter have equaled the power saving.

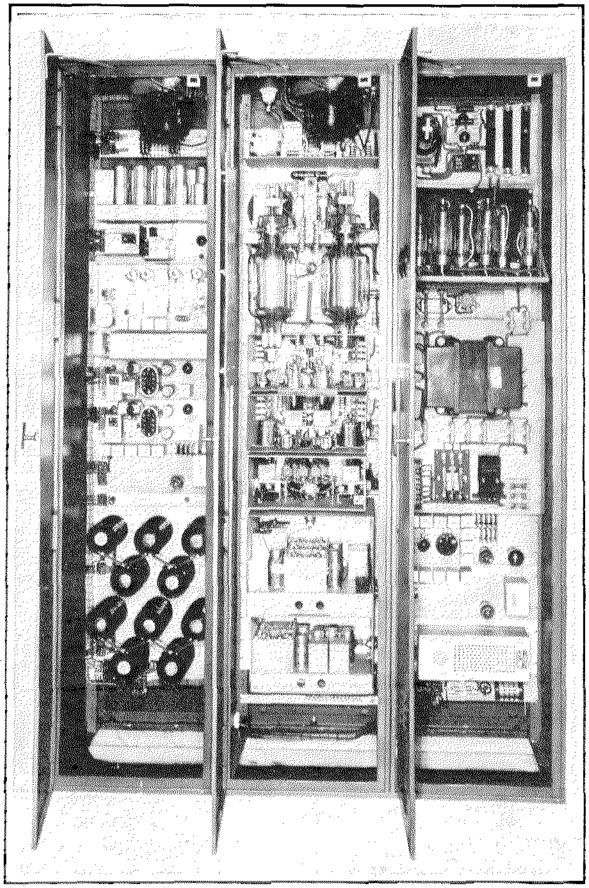
In the case of the double sideband equipment, commercial records over the past ten years showed an average of 94% chargeable time, i.e., the ratio of the paid time to the total talking time; the percentage of time that the circuit was available for traffic was 98%, i.e., the ratio of the commercially usable time to the total scheduled time. During the past year this record has been equaled with the single sideband low power equipment. Credit for these high percentages is due in part to the fact that conditions on the north-south path utilized are superior to those ordinarily encountered on long haul radio circuits. While CIDRA has been gratified with the improved performance with the single sideband, it has been especially pleased with subscribers' reaction, resulting from the high quality of the circuit as well as from more rapid completion of calls and prompt conveying of information to calling parties.

In addition to decreased tube replacements and reduced power consumption, economy of operation has been effected by means of the semi-automatic terminal equipment which, for long intervals, requires practically no attention from the technical operator. One attendant can easily monitor two circuits even during most unfavorable periods when wave changes, etc., are frequent, while during normal hours, he can readily handle eight to ten circuits. Moreover, the



Front View of Transmitter.

Left Bay: Voltage regulator, a-c power transformer, rectifiers, and other low frequency units.
Center Bay: High frequency circuits, power amplifier, antenna outlet.
Right Bay: Dry rectifiers, audio frequency panels, modulators, etc.



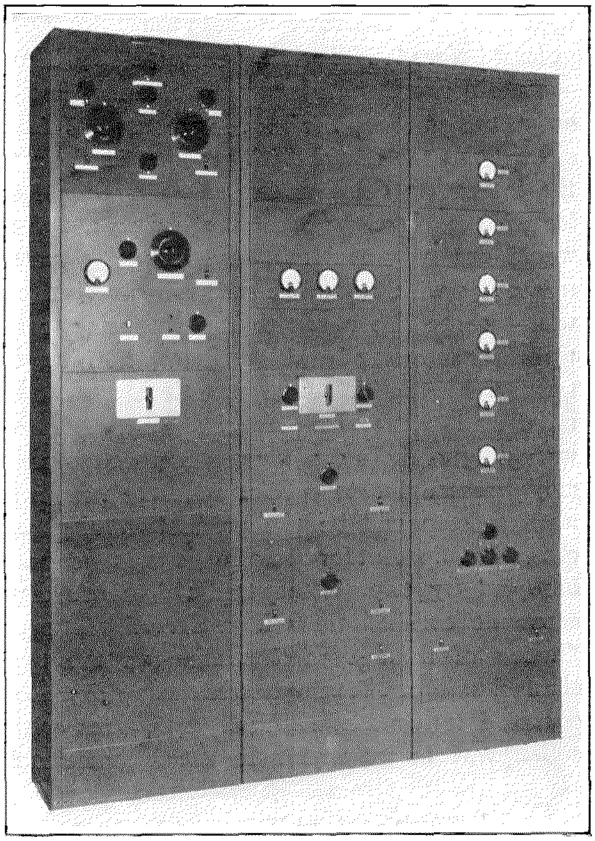
Rear View of Transmitter.

Right Bay: Voltage regulator, a-c power transformer, rectifiers and other low frequency units.
Center Bay: High frequency circuits, power amplifier, antenna outlet.
Left Bay: Dry rectifiers, audio frequency panels, modulators, etc.

automatic terminal gives better results than hand operation since automatic gain control circuits follow fluctuations in level accurately and without noticeable delay, whereas a very appreciable delay in gain control occurs when the eye and the hand attempt to keep pace with changing speech volume from two subscribers, circuit fluctuations, etc.

The transmitter includes a special panel for quick switching to double sideband operation when needed to work stations not equipped with single sideband receivers. It is also equipped with a special transmission line arranged so that the last two stages of the old double sideband transmitter can be driven as a power amplifier during poor transmission periods. The envelope peak power into the antenna with the S.S.B. unit is normally 2 kw while, with the power amplifier, it can be boosted to 80 kw, a ratio of 40 : 1, i.e., a power gain of 16 db which is very noticeable under poor transmission conditions which usually continue for an hour or so at Buenos Aires or New York during the summer evening transition periods around 6 p.m. In general, the amplifier is used also in connection with broadcast programs to insure the highest possible signal to noise ratio.

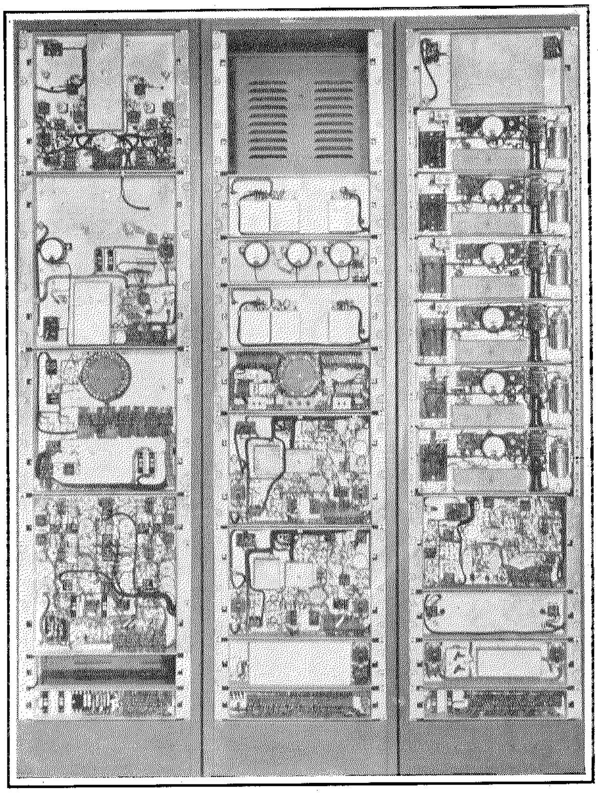
In point-to-point transmission of broadcast programs the new equipment has given excellent results. Overall frequency runs, with the privacy equipment disconnected, have shown the audio characteristic to be practically flat within ±1 db from 50 to 6,000 cycles. Moreover, selective fading and certain types of background noise, always heard on the double sideband circuits, are practically absent from the single sideband channels. To insure good control of the programs the second channel is rarely in traffic, the channel being used for circuit monitoring and studio contacts between the two terminals.



Front View of Receiver Showing Instrument and Control Panels.

On the receive side of the terminal a noise reducer is invariably in service and, when transmission conditions are poor, it gives an improvement of from 8 to 10 db in noise level. To maintain constant level into the terminal, a receiving VOGAD at the output terminals of the receiver aids appreciably in the operation of the circuits. The equipment provides two voice frequency channels 3,000 cycles wide or one voice channel and one wide band broadcast channel. Two broadcast quality channels cannot be operated simultaneously at present but it is not improbable that some solution may be found to this problem. When the two voice frequency channels are in use, one of them is displaced 2,650 cycles out from the carrier by a band spreader in the transmitter side of the terminal and, correspondingly, in the associated receiver output, the voice channel is shifted back by another unit which restores the voice channel back to its original position. Incidentally, prior to June, 1938, twin channel short wave equipment of this type was not in commercial use in the U.S.A. and, at least before 1937, had not been used elsewhere.

Since the earliest days of radio communication one of the problems has been to procure sufficient channels in the ether. With progress in the art, the increasing demand for added circuits has forced the development of equipment which would not only maintain its assigned channel frequency with negligible variation but which would carry the required intelligence in continually narrowing bands within the radio spectrum. With the history of past development in mind and with memories of long months of wrangling at radio conferences, it would appear not unreasonable to predict that the next immediate step will be the production of three channel equipment for operation in the space now occupied by two. When traffic demands and economic considerations have forced the production of three channel equipment, the two channel units can be relegated to the position now occupied by double sideband equipment with consequent improvement in the international radiotelephone service, which has been showing a steady and healthy growth during recent years.



Front View of Receiver with Cover Panels Removed.

Left Bay: Upper panel contains the high frequency amplifier and first detector; second panel, the first beating oscillator; third panel, intermediate frequency amplifier and second detector; fourth panel, automatic tuning control.

Center Bay: Contains meters, monitoring control and channel amplifiers.

Right Bay: Second beating oscillator and 6 panels for rectifiers.

Since May, 1941, over 250 broadcast programs have been handled with the new equipment, of which 248 were classed "good" to "very good."

The performance of the new equipment has been so highly satisfactory that it was decided early in 1941 to install twin channel equipment on several other circuits where traffic demands and speed of service can no longer be met with a single channel equipment. The Rio de Janeiro–New York and new San Juan, Puerto Rico–New York circuits will both be supplied with similar equipment. Indications are that they will be opened for service in the relatively near future.

Durand Hospital Signaling and Communication Equipment

By W. WHITE
Compañía Standard Electric Argentina, Buenos Aires, Argentina

DURAND HOSPITAL, probably the largest institution of its kind in South America, was opened recently and is outstanding for the completeness and modernity of its building and equipment. It contains some 650 beds and is fitted with specialized facilities, such as theatres, both for clinical practice and experimental research. Signaling and communication systems, provided and installed by Standard Electric Argentina, are of a standard in keeping with the equipment as a whole. The more interesting features of these systems are described in this article.

Telephone System

Internal telephone facilities are furnished by a Bell Telephone Manufacturing Company type 7055 PABX (Fig. 1), at present equipped for 150 lines and 15 connecting circuits; the ultimate capacity is 200 lines. Code calling equipment provides a capacity of 30 codes, and code display boards are installed on all ten floors of the building. PAX conference facilities enable the Director of the Hospital to call into conference any group of predetermined individuals. Most of the telephone sets are ivory finished, thus

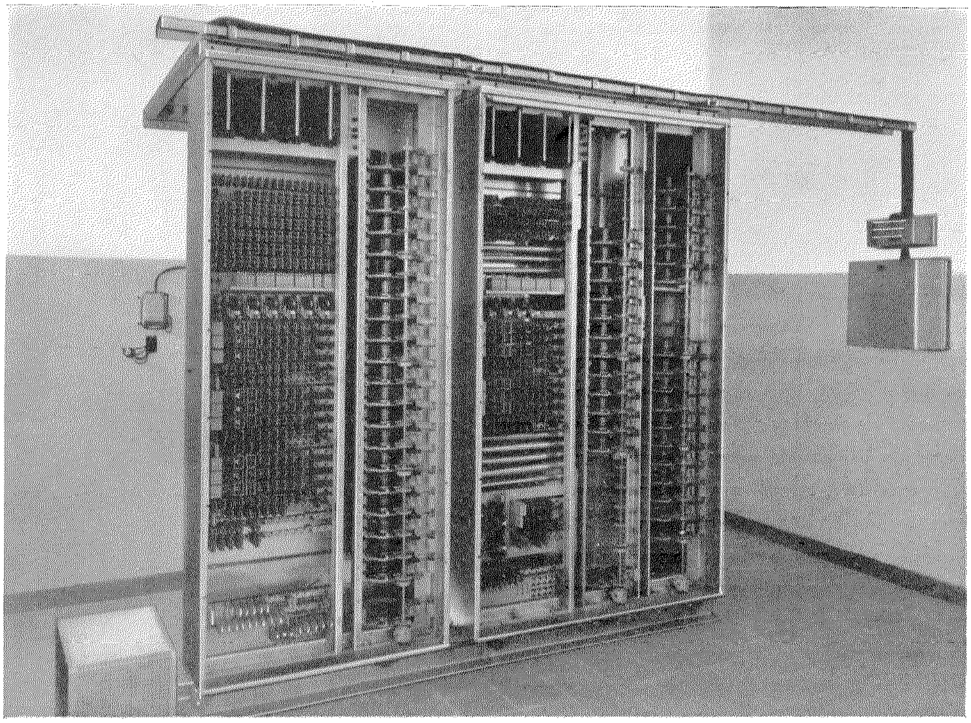


Fig. 1—Type 7055 PABX.

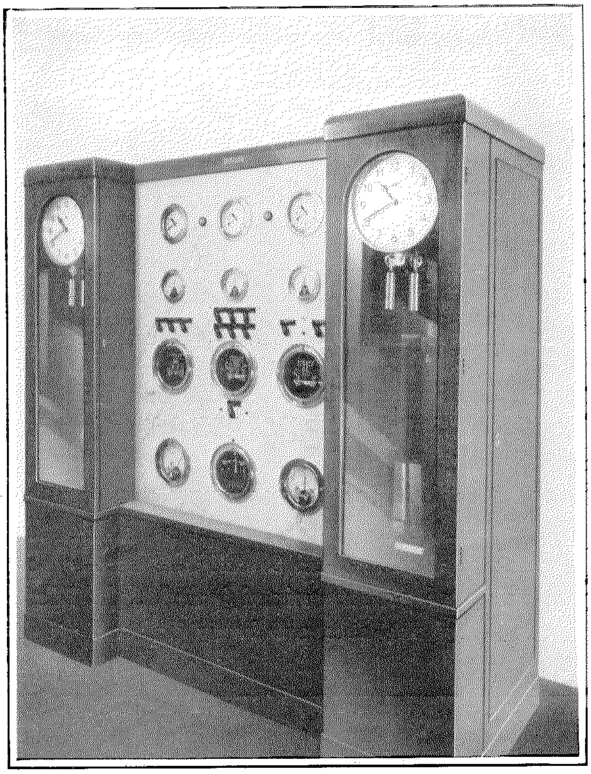


Fig. 2—Electric Clock System—Central Installation.

contributing to the immaculate appearance of the Hospital.

Electric Clock System

One hundred and thirty secondary clocks with a specified accuracy of ± 10 seconds per month for the system are installed throughout the building. They are controlled by a master clock arranged for automatic change-over to a standby master clock. The secondary clocks are divided into three individually controlled circuits. Fig. 2 gives a general view of the central installation.

Seven chronometers are provided for use in the seven operating theatres. These are seconds clocks and can be started and stopped at will; restoration to normal setting is accomplished by the operation of a foot pedal. Five date and time stamping clocks also are connected into the secondary clock circuit for control of correspondence and patients' records.

The entire system is operated from a separate 24 volt storage battery with a capacity of 12 hours of operation in case of emergency. The battery is operated on the full float principle from a selenium type rectifier.

Patients' Calling System

This system permits patients' calling either one or both of two attendants and gives the following control indications:

A call results in lighting a lamp in the patient's room, another outside the door of his room and a group lamp designating the group of the calling room; in addition, a floor indicator is

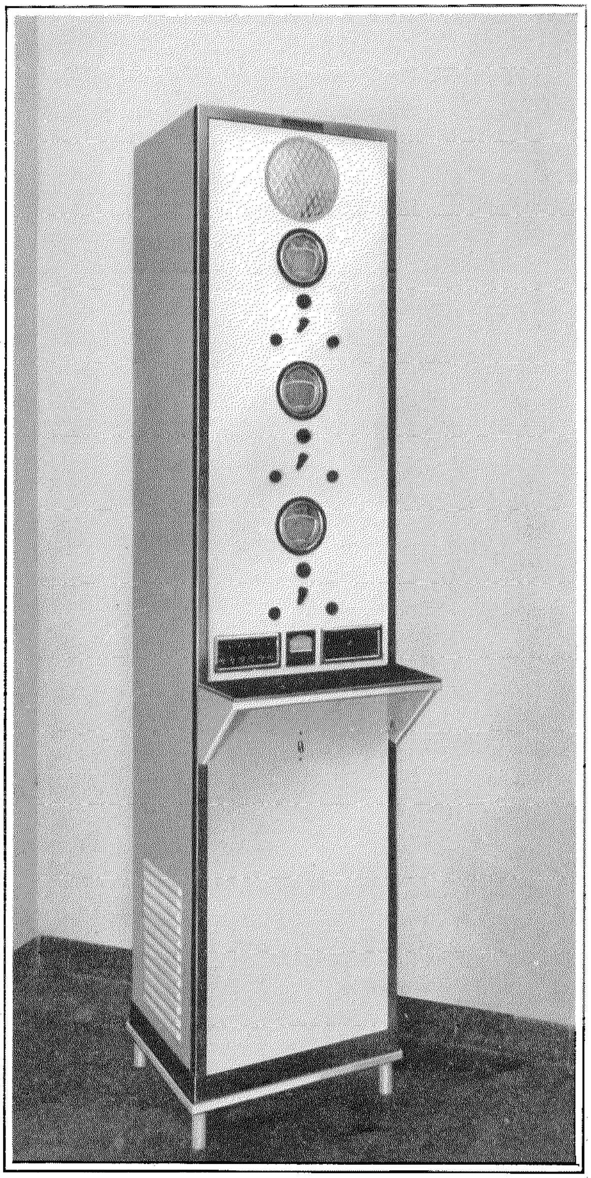


Fig. 3—Radio Receiving Equipment.

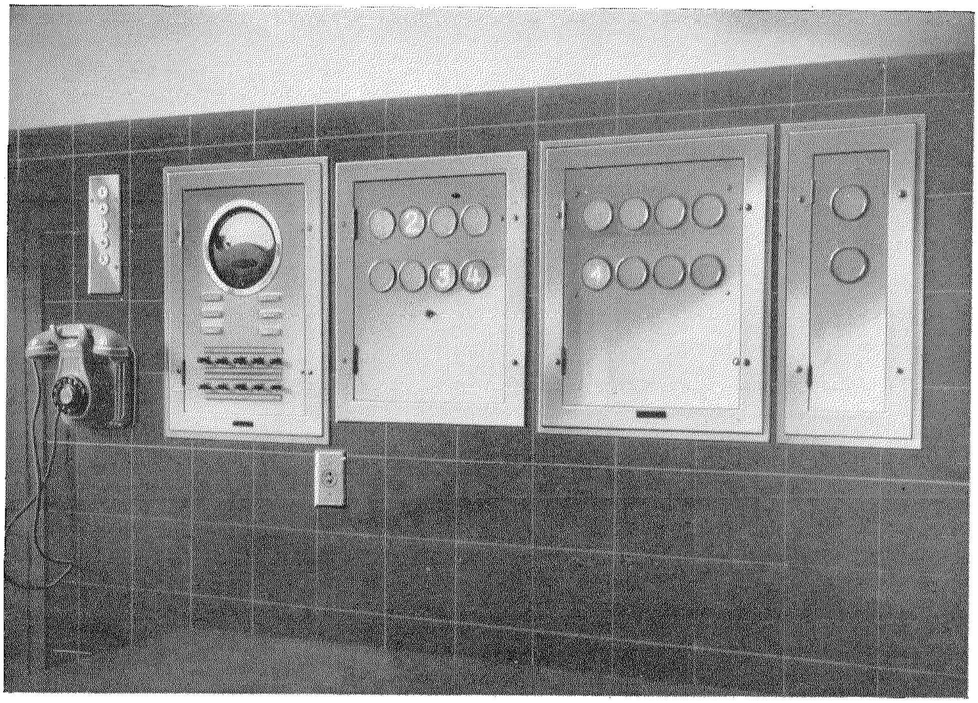


Fig. 4—Remote Temperature Indicator.

used during the night when the personnel is reduced. An audible alarm is sounded intermittently until a call is answered.

The calling system employs relay equipment of the mechanical lock-up type. The operated condition is maintained until the reset button in the patient's room is depressed, thus ensuring prompt attention to all calls.

For observation purposes all circuits are terminated in a central switchboard. As many as 40 circuits can be connected simultaneously, by means of plugs and cords, to register equipments which furnish a printed record of the time consumed in answering individual calls. Registers are individual to each circuit; the chart on which the record appears is driven from a secondary clock circuit.

Radio System

Radio facilities accessible to all rooms are provided by a centralized program distribution system. Patients can select programs by means of a three point switch. Head phones, loudspeakers or bone conduction receivers can be used at any point. The three feed line circuits are of the constant impedance type, independent of the number of receiving equipments connected; they are fed from three all-wave receivers and amplifiers (Fig. 3), capable of supplying 60 watts to each line. The receiver caps are of a special design facilitating disinfection.

For giving instructions of a general nature to the Hospital personnel, an additional amplifier system was installed. Microphone points are provided in the Administrator's Office and in the Director's office; loudspeakers are located in the staff's quarters on each floor. A switching arrangement gives the Director control of the system even when in use from the other microphone point. The amplifier is designed to deliver 60 watts to the loudspeaker line.

Remote Temperature Indicator System

Five central indicator boards are located on different floors of the building; each board has a capacity of twenty circuits, an average of sixteen being connected at present. Thermometer elements are installed in patients' rooms, the arrangement being such that room temperatures can be read by depressing appropriate keys on the central equipment. The system operates on the Wheatstone bridge principle; the meter reading is the result of unbalances due to temperature effects on the resistance coils located in the patient's room. A small Selenium Rectifier supplies the required voltage which is regulated within close limits by means of a ballast lamp. Fig. 4 illustrates a typical equipment.

Out-patients' Indicator System

Each consulting room of the out-patients' section is fitted with facilities enabling the physician to call any patient from a central board on which his consulting room and the patient's number are indicated. The numbers are displayed on a ground glass screen through the medium of a form of hand-operated sequence switch and a group of lamps mounted in a bakelite moulding.

Similar display boards, as illustrated by Fig. 5, are mounted over the doors of individual consulting rooms.

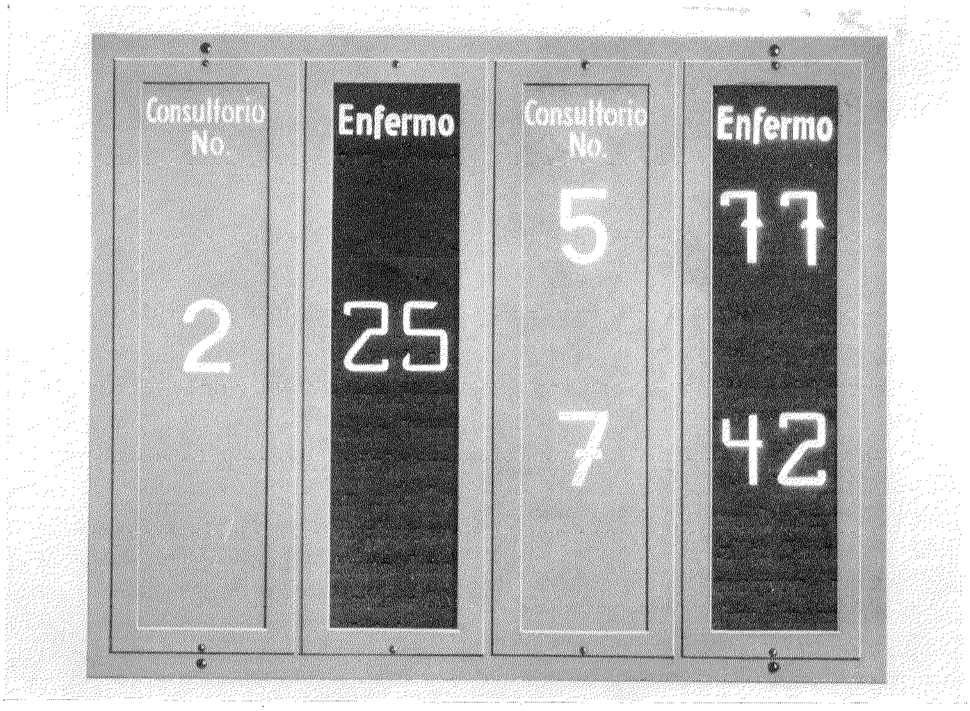


Fig. 5—Patients' Call Indicator.

Design of the Output Stage of a High Power Television Transmitter

By E. LABIN

Laboratories, International Telephone & Radio Manufacturing Corporation, New York, N. Y.

Introduction

THE Eiffel Tower Television Transmitter, built by Laboratoires Le Matériel Téléphonique in 1937 and 1938 for the French PTT Administration, operated with a peak power of 36 kw at a frequency of 46 megacycles. The modulation frequency band was 0–2.5 mc, giving a total high frequency band width of 5 mc. At that time it was, and it probably still is, the most powerful television transmitter in the world.

The present article is an abstract of a paper written in 1938 and read before the Société Française des Electriciens. The latter paper described the output stages of the transmitter with a more technical approach to this portion of the transmitter problem than was attempted in an article previously published in *Electrical Communication.*[1] In the present abstract some parts of the original S.F.E. paper dealing with special television and modulation problems have been omitted since they are now of minor interest due to the introduction of single side band transmission and an increase in the number of scanning lines. The problem of a wide band modulated output stage for ultra-high frequency service, however, appears to be of interest, and this article is, therefore, presented.

The first part of this article deals with generalities pertaining to the modulation system and the choice of output tubes. The second part contains details of the inverted amplifier circuit with the grid-reactance neutralization adopted for the transmitter, and the third part includes experimental data collected in the tests on the equipment.

I. General Output Stage Problems

1. MODULATION SYSTEM

To determine the characteristics of the output stage it is first necessary to decide on the method of modulation. The wide frequency band required leaves very little choice in this decision.

Modulation by absorption in the output circuit has been used successfully in low power applications, but for high power use the difficulties would appear to increase greatly without compensating advantages.

Modulation systems at low level considerably reduce the modulator problem, but lead to a system of wide band linear amplifiers which might be justified in single side band systems, but not for a symmetrical modulation system.

Plate modulation of the output stage is one of the best methods in normal broadcasting, where class B modulators may be used, but a transformer suitable for plate modulation with a wide frequency band has not yet been achieved.

The remaining modulation method, that of modulating the grid bias voltage of the output stage, is that used on the Eiffel Tower transmitter, as it is in almost all existing television transmitters.

It does not necessarily follow, however, that this means low modulation power. The power is not determined by the grid power requirements of the output stage, but rather by the capacity of the grid circuit to ground. This capacity is in shunt across the output of the modulator, whose output impedance at high frequency must be at most equal to the reactance of the capacity to ground. If this capacity is about 120 mmfd., and it can hardly be less due to the large physical dimensions of the circuit elements, the modulator output impedance must not be more than 500 ohms (500 ohms is the reactance of 120 mmfd. at 3 MC/S). A potential variation of about 3000 volts peak-to-peak is needed, requiring a modulator output of 2.25 kw. Since the modulator operates as a class A amplifier, a tube must be used capable of a plate dissipation of about 12 kw. The LMT tube 3053-A fulfills these conditions and was the tube used in the Eiffel Tower modulator.

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[1] "The Eiffel Tower Television Transmitter," by G. Rabuteau and S. Mallein, *Electrical Communication*, Vol. 17, No. 4, 1939.

The use of grid modulation adapts itself well to the need for varying the carrier to keep a constant black level. A diode at the grid of the modulating stage detects the modulating signal and causes the anode current of the modulator to vary with the average picture brightness. Thus the modulator effectively amplifies all frequencies from 0 to 2.5 mc. The plate of the modulator tube is tied directly to the grids of the output stage. The average bias of the output stage is adjusted by a bias rectifier connected between the filaments and ground.

2. DISTORTION DUE TO PLATE CIRCUIT AND CHOICE OF OUTPUT STAGE TUBE

The variation in grid voltage produced by the modulator creates side bands in the anode current in addition to the normal carrier frequency. In order that the output of these components be constant, it is necessary (but not sufficient) that the plate circuit impedance vary little over the frequency range occupied by these side bands. If the plate circuit is compared to a simple tuned circuit consisting of an inductance L, a capacity C and a parallel resistance R, the Q of the circuit will be R/Lw and deviation of df from the resonant frequency f_0, such that

$$\frac{df}{f_0}=\pm\frac{1}{2Q}\%$$

will introduce an amplitude distortion of 3 db and a transmission delay of $\frac{.1}{4\pi df}$ seconds. That is to say, for a carrier frequency f_0 of 46 mc and a maximum modulation frequency f of 3 mc, the Q should not exceed

$$Q=46/6=7.5$$

if the distortion is to remain less than 3 db and 30 millimicroseconds.

The impedance of the plate circuit at resonance is given by the formula

$$R=Q/C\omega_0=\frac{1}{4\pi Cdf}. \qquad (1)$$

With the large modulation band employed, the value of R obtained from (1) is generally less than the optimum value for the tubes. This means that in television the frequency band will determine the output impedance, and hence the type of tube to be used in the output stage.

Assuming that the output stage consists of two tubes connected in push-pull and operating in class B under peak conditions, and that the peak current available for the plate is .8 of the saturation current I_s, the saturation current necessary to obtain a peak power output of P kilowatts with a modulation band of f mc and a total circuit capacity of C mmfd. will be

$$I_s=.4\sqrt{PCf}. \qquad (2)$$

For example, if a power of 36 kw and band width of 3 mc is required for an output capacity of 18 mmfd., the saturation current necessary per tube will be 17.5 amperes.

These conditions are satisfied in the Eiffel Tower transmitter by the use of two LMT tubes types 3084-A.

3. COMPLETE CIRCUIT OF THE OUTPUT STAGE

It is at first rather surprising that the above equations do not contain a term depending on the frequency of the carrier. However, other requirements must be met in order to ensure proper wide band operation beside that of a low Q output circuit:

(*a*) The coupling transformer to the transmission line must have a wide band characteristic;
(*b*) Neutralization must hold over the complete band;
(*c*) The effects of stray coupling existing in several actual reactances should be reduced to a minimum or judiciously used.

All of these conditions depend on the relative width of the band as well as on its absolute value, and become increasingly simple to satisfy as its relative width decreases.

The output transformer will not be discussed here since its theory is well known and the relative width of the band is not even as large as that in some coupling transformers for receiver intermediate-frequency amplifiers. Similarly, the antenna and transmission line will not be considered inasmuch as an explanation of

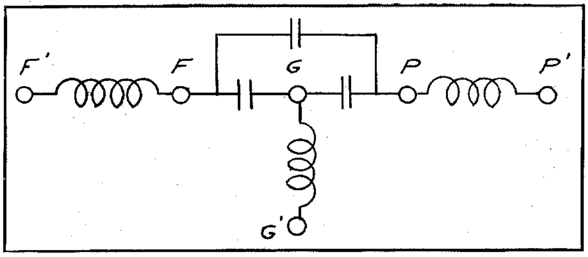


Fig. 1.

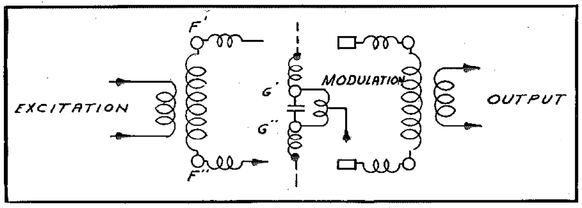


Fig. 2.

their design is considered outside the scope of this article. Points (*b*) and (*c*), however, concern the output stage itself and will be fully discussed.

We may admit that, in the frequency band around 46 mc, a triode must be replaced by a network of six reactances arranged as shown in Fig. 1. The circuit includes in addition to the three inter-electrode capacities, series inductances between the "true" terminals F, G, and P, and the accessible terminals F', G', and P'.

Actually such "true" terminals cannot be designated since the complete geometrical structure of a vacuum tube cannot be strictly represented by a network formed of lumped elements. The network indicated, however, represents a sufficiently good approximation for the frequency range and tube dimensions under consideration.

If a classical amplifier circuit is used with the tubes in push-pull neutralized by capacities in a balanced bridge and excited between the grids, it will be found necessary to ensure adequate neutralization over the band to compensate the grid series inductances inside the tubes by series condensers. At the high power being considered these condensers would constitute a capacitive load on the modulator that would not be negligible.

Feedback in the series inductance of the internal filament inductance is not compensated and might create difficulty in realizing the wide band operation desired.

The anode circuit capacity across the output circuit is very large, its minimum value being at least equal to C_{pg} plus $C_{pf}/2$ (without including the self capacity of the neutralizing and series condensers).

Another disadvantage of this classical circuit for grid modulation is that the modulation of the excitation is opposed to the total modulation of the stage. (When the grid becomes very negative the excitation increases and the voltage necessary to complete cutoff is larger than would be the case for a perfectly regulated excitation source.) This means that considerable excitation power must be dissipated in "swamping resistors" to improve the linearity.

II. Inverted Amplifier Circuit

1. Static Conditions

The difficulties in neutralization and large circuit capacity indicated above lead to an inversion of the standard circuit to one in which the excitation is applied to the filaments, with modulation always applied to the grids. The system is indicated schematically in Fig. 2.

Neutralization may now be effected by balancing the plate-filament capacities, which are much lower than those between plate and grid. This system offers considerable advantage over the standard grid-excited system, but it is preferable, particularly in wide band applications, to neutralize with a suitable reactance placed between G' and G''.

Considering only the upper half of Fig. 2, Fig. 3 is obtained, in which M represents the neutral plane of symmetry. In Fig. 3 the internal filament and plate inductances have been included in the external impedances Z and Z'. Fig. 3 is a particular case of the bridged T shown in Fig. 4, in which

Z_1, Z_2, Z_3, and Z_4, represent any impedances;
Z and Z' are the terminal impedances;
Z_{12} is the impedance seen from terminals 1 and 2 when terminated in Z';
Z_{34} is the impedance seen from terminals 3 and 4 when terminated in Z;
I is the current which enters the network;
I' is the current which leaves the network.

In order to realize proper neutralization in the circuits of Figs. 2 and 3, it is necessary and sufficient that the reactances be in such relation that in the equivalent T of Fig. 4 current I' shall be zero for all values of I (or inversely that I shall be zero for all values of I'). It may be argued that while the current from plate to ground is zero, there is a current flowing from plate to filament. This is true, but obviously no oscillation may be sustained if no current flows in the external circuit.

The condition for neutralization is equivalent to the balanced condition for the bridged T network. This condition may be easily found by applying Kirschhoff's laws or by resolving the system by the general method of determinants. The balanced condition may be written

$$Z_4 = -\frac{Z_1Z_2}{Z_1+Z_2+Z_3}. \qquad (3)$$

When the bridge is balanced, the impedances Z_{12} and Z_{34} are independent of the terminating impedances, and their values may be obtained by assuming Z' and Z to be infinite, whence

$$\begin{aligned} Z_{12} &= Z_1\frac{Z_3}{Z_1+Z_2+Z_3}, \\ Z_{34} &= Z_2\frac{Z_3}{Z_1+Z_2+Z_3}. \end{aligned} \qquad (4)$$

If the general formulas (3) and (4) are applied to the neutralization of the inverted amplifier, we shall find that if the impedances Z_1, Z_2, and Z_3 are of the form:

$$Z_1 = \frac{1}{jC_1\omega}, \qquad Z_2 = \frac{1}{jC_2\omega}, \qquad Z_3 = \frac{1}{jC_3\omega},$$

the grid reactance Z_4 must be an inductance L defined by equation (5); and the input and output impedances are capacities C'_1 and C'_2 which are given by equations (5),

$$\begin{aligned} &L = 1/Kw^2, \qquad K = C_1C_2/k, \\ &1/k = 1/C_1 + 1/C_2 + 1/C_3, \qquad (5) \\ &C'_1 = C_1C_2/k, \qquad C'_2 = C_2C_3/k, \end{aligned}$$

$$C_1 = C_{fg}, \qquad C_2 = C_{gp}, \qquad C_3 = C_{pf}. \qquad (6)$$

For the type 3084-A tube

$$C_{fg} = 25.5 \text{ mmfd.}, \qquad C_{gp} = 23.5 \text{ mmfd.},$$
$$C_{fp} = 6.5 \text{ mmfd.},$$
$$k = 100/23.5, \qquad K = 140 \text{ mmfd.};$$

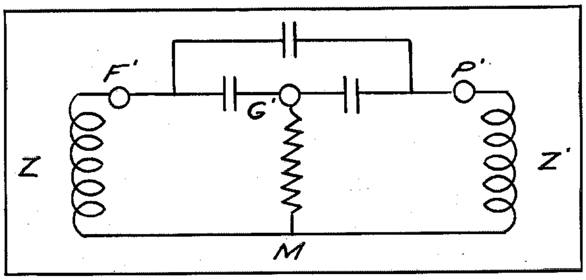


Fig. 3.

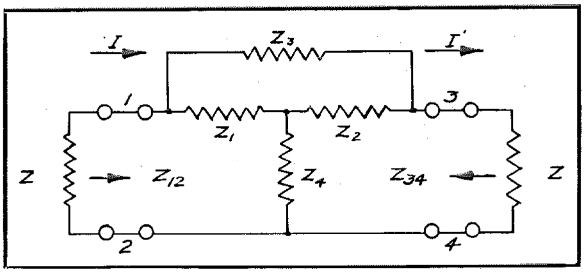


Fig. 4.

whence

$$L = 84 \text{ millimicrohenries},$$
$$C'_1 = 1.53\ C_{gf} \text{ or } 39 \text{ mmfd.},$$
$$C'_2 = 1.53\ C_{gp} \text{ or } 36 \text{ mmfd.}$$

For the same tube the classical circuit gives an anode circuit capacity $C''_2 = 2.27\ C_{gp}$.

The ratio $b = C''_2/C'_2 = 1.5$ illustrates the advantage of the inverted circuit over the classical one. It shows that for an equal pass band, the plate impedance may be 50% greater, or that the output power will be about 50% more.

As a general rule, b is given by the formula

$$b = 1 + \frac{1 - C_{pf}/C_{gf}}{1 + C_{pf}/C_{gf} + C_{pf}/C_{gp}}.$$

The advantage becomes greater as the plate-filament capacity decreases. The maximum value of b is 2, but in general it will be in the neighborhood of 1.5.

The neutralizing inductance L, found from equation (5) for the LMT 3084-A tubes and a carrier frequency of 46 mc, is smaller than the actual grid internal series inductance. This internal inductance is .12 microhenries and, with the necessary external leads, reaches almost .2 microhenries. It is necessary, therefore, to introduce a capacity between the grids for neutralization. This capacity has two disadvantages:

(*a*) The reactance between the grids formed by an inductance and capacity in series varies more rapidly than it would for an inductance alone, and neutralization is not strictly maintained over the entire frequency band. It will be seen later, however, that this effect is corrected by the inherent negative feedback present in the inverted amplifier.

(*b*) The condenser must carry a circulating current which is the sum of the plate and filament circulating currents and which may reach a very high value. The self-capacity of a condenser of the required physical size will be shunted across the modulator output and adversely affect its performance. At the Eiffel Tower, this condenser was replaced by a quarter-wave line terminated by a variable inductance. This combination has a capacity to ground 40 percent less than that of an equivalent condenser.

2. Dynamic Operation

Once the grid impedance has been fixed by the condition for neutralization, the dynamic operation of the unit depends not only on the excitation voltage and the plate impedance, but also on the negative feedback which is developed across the input impedance due to the flow of emission current through it, and on the positive feedback across the grid impedance.

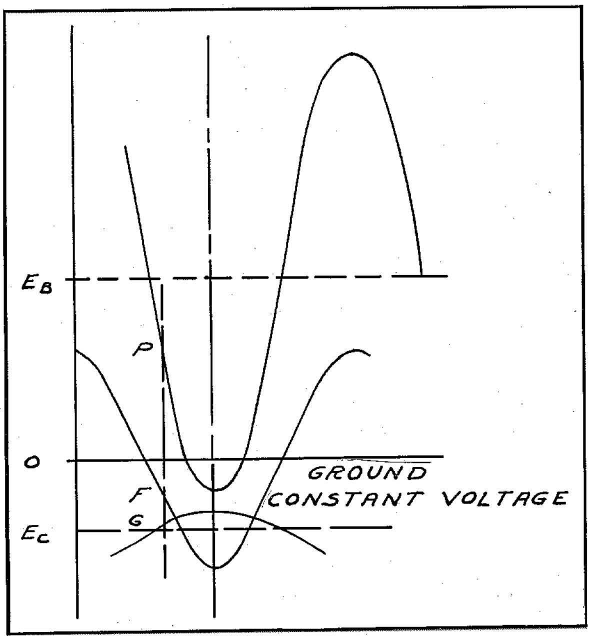


Fig. 5.

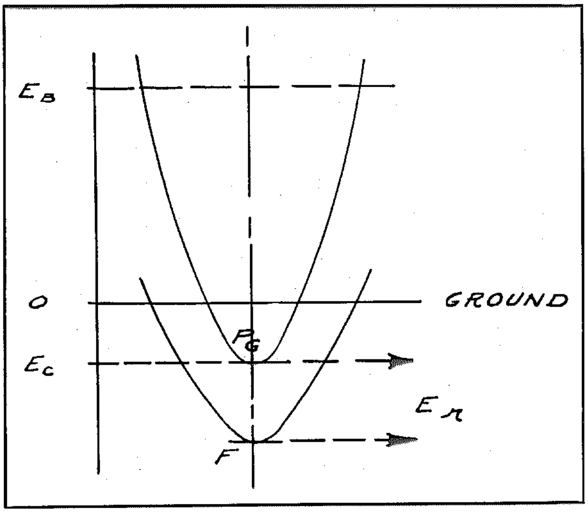


Fig. 6.

Figs. 5 and 6 show the ideal variation of the voltages between the three electrodes and ground, assuming that the voltages are either exactly in phase or in phase opposition. E_b represents the direct plate voltage and $-E_c$ the direct grid voltage; the filament is assumed to be at ground potential for direct current.

The maximum plate voltage swing may be obtained as in the standard circuit by assuming that at the instant of maximum current the plate and grid are at the same potential. The filament-grid and filament-plate voltages will then be

$$V_{pf}=V_{gf}=E_r \quad \text{and} \quad V_{pg}=0,$$

where E_r represents the residual plate voltage required to draw the required maximum current (in this case assumed as .8 I_s) from the filament.

It may be seen that for filament excitation the alternating plate voltage is not limited to the value (E_b-E_r), but may reach E_b or even exceed it. The limiting value will be E_b+E_c for an alternating grid voltage of zero.

This condition cannot be realized except for zero impedance from grid to ground and, therefore, will not be met when neutralization is effected by placing a reactance between the grids; it is, however, possible if standard bridge neutralization is used. In this case the filament excited circuit allows full use of the power supply voltage, permitting very high efficiencies (theoretically better than 100%) if the efficiency be defined as the ratio between the high frequency power available at the output and the direct power applied to the plate. The high output is actually due to the power transferred from the excitation source to the output circuit.

The driver, in addition to supplying the excitation voltage, also feeds power to the output load through the resistance of the output tubes.

Another reason for the need of large excitation power is that, in the inverted amplifier, the emission current flowing through the filament circuit impedance creates a negative feedback so that additional power is required to maintain the voltage E_r between filament and grid. The excess power will depend upon the input impedance of the output stage. Due to this negative feedback, the impedance in the filament circuit plays an important role in determining the passband of the amplifier.

As an illustration of the way in which reactions are balanced the circuit of Fig. 5 will be considered. In this case the amplifier is neutralized with a grid reactance so that the impedance between the grids is appreciable, and it will be shown that an operating condition may be set in which the various reactions practically cancel out. The result is that the plate current depends essentially only on the excitation voltage and varies with frequency as does this voltage.

We shall consider E_x as the excitation voltage present when no anode current flows, I_1 the fundamental frequency component of the plate current, and Z_{fm} and Z_{pm}, respectively, the impedances between filament and ground and plate and ground, which will be assumed as zero for the harmonics of I_1. We will designate by m_f and m_p, respectively, the portions of the filament and plate voltages which are across the grid impedance.

When the bridged T is balanced, the components m_f and m_p may be calculated by the formulas:

$$m_f=-C_{pf}/C_{pg}, \qquad m_p=-C_{pf}/C_{fg}. \tag{7}$$

From the definition of m_f and m_p we may also obtain the formula

$$V_g=V_p m_p+V_f m_f, \tag{8}$$

where the single subscripts g, p, and f indicate the voltage from the tube element to ground.

Further, the operating condition of the stage is determined by the control voltage and tube characteristics so that the plate current is a function of

$$V_{gf}+\frac{V_{pf}}{\mu}$$

only, where μ is the amplification factor of the tube.

The following equations are then obtained directly:

$$\begin{aligned} V_p&=-(E_x-I_1Z_f),\\ V_p&=-I_1Z_p,\\ V_{gp}&=V_g-V_p,\\ V_{pf}&=V_p-V_f, \end{aligned} \tag{9}$$

and the formula for the control voltage becomes

$$\begin{aligned} V_{gf}+V_{pf}/\mu=&E_x(1-m_f)+E_x/\mu\\ &-I_1[Z_p(m_p+1/\mu)-(m_f-1-1/\mu)Z_f]. \end{aligned} \tag{10}$$

Equation (10) indicates that it is possible to adjust the ratio of anode and filament impedances in a manner such that the control voltage will not depend upon the anode current. This condition of reactance compensation is obtained when the coefficient of I_1 in equation (10) is reduced to zero, or when

$$\frac{Z_f}{Z_p}=\frac{m_p+1/\mu}{m_f-1-1/\mu}. \tag{11}$$

For the 3084-A tube, the values found for m_f and m_p from equation (7) lead to the equation

$$Z_p=5Z_f. \tag{12}$$

Thus the variation of the filament impedance with frequency follows the same law as the plate circuit impedance variation, i.e., the Q's of the two circuits should be equal. This may be accomplished by appropriate loading of the input circuit.

Equation (12) must be considered an approximation since the reactance in the grid circuit does not ensure neutralization over the whole frequency band. The values of m_f and m_p apply only to the carrier condition, whereas variation actually occurs over the entire frequency band.

If the variations in these two factors are sufficiently slow, it is possible to fulfill the conditions of equation (11) by detuning Z_{fm} and Z_{pm} slightly, even when the reactance between the grids is not exactly that imposed by equations (5).

For a given grid reactance, the relative regulation of the filament and plate impedances may be changed to expand or contract the passband of the stage as desired. It must be understood, however, that this will be accompanied by a corresponding decrease or increase in output power.

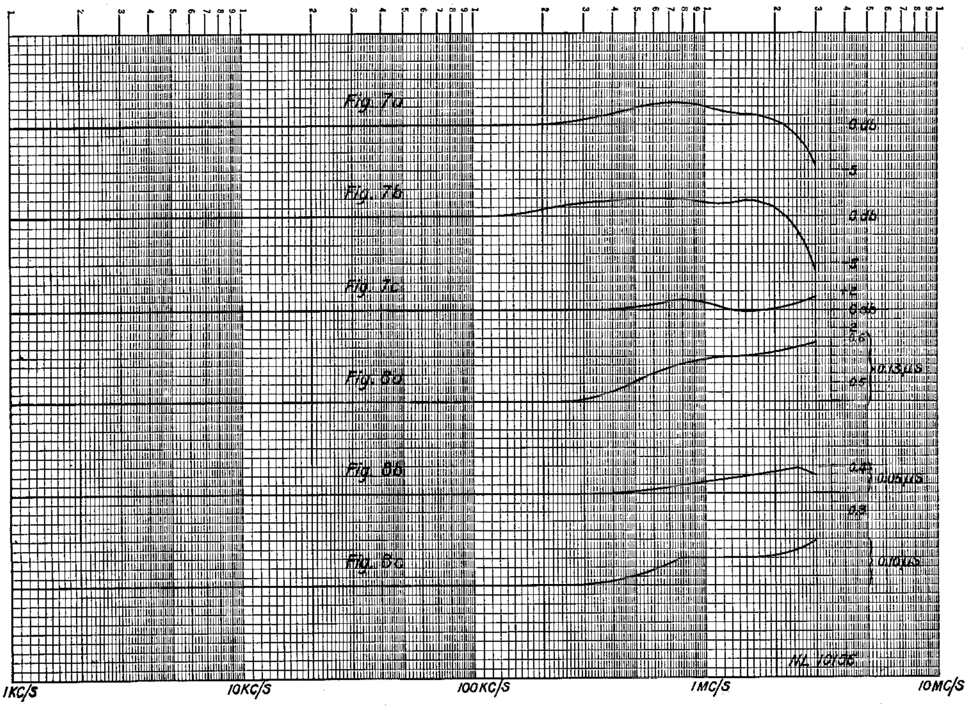
A more complete theory of the amplifier adjusted as shown above may be developed by expanding coefficients m_f and m_p to include their variation with frequency. The calculations, however, are laborious and it would appear preferable to use simply the approximate solution given above. This is entirely adequate, since it allows an estimate of the direction of variation of the various elements. Furthermore, a more precise theory giving the exact impedance values would be somewhat illusory considering the initial approximations and the accuracy with which the tube reactances may be determined.

The detuning of the plate and filament impedances allows a constant modulation depth at all frequencies, but has a tendency to introduce delay distortion.

In the foregoing discussion only the frequency response of the modulated amplifier has been considered.

The linearity of modulation is less important in television than in speech and program broadcasting, but it is still advisable to be able to reduce the carrier to zero without the necessity for excessive modulating voltage. This zero carrier condition corresponds to the base of the synchronizing pulses in the European standards and to a full white image in the American standards.

The excitation of the filament circuit through a quarter-wave line allows linearity to be approached in the low carrier region inasmuch as the excitation has a tendency to decrease at the same time the plate current decreases. This is due to the fact that a quarter-wave line inverses impedances so that, when the input impedance at the filaments increases, the load on the driver



Figs. 7 and 8.

also increases. In the Eiffel Tower transmitter, linearity is equally good at both ends of the modulation characteristic despite the use of grid modulation. The result is that the transmitter may be used equally well for transmission with positive or negative systems (European or American standard).

III. Experimental Results

The following curves indicate the distortion introduced in the modulated amplifier:

Fig. 7a shows the frequency-amplitude response characteristic of the complete transmitter measured between the input terminals of the modulator and the output terminals of a detector coupled to the transmission line feeding the antenna. The errors introduced by the detector are negligible for modulation frequencies up to 3.5 megacycles.

In this figure, zero level corresponds to 50 percent modulation of the carrier. The input level to the modulator is .5 volts rms.

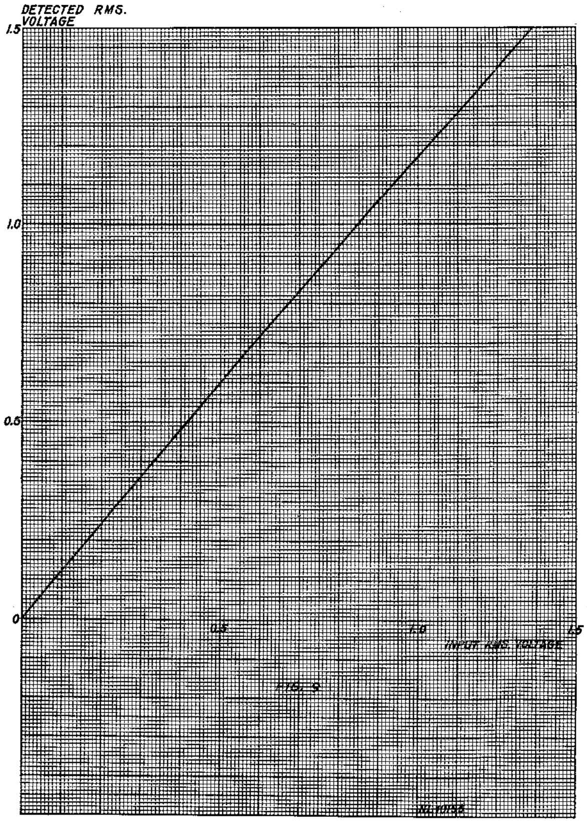


Fig. 9.

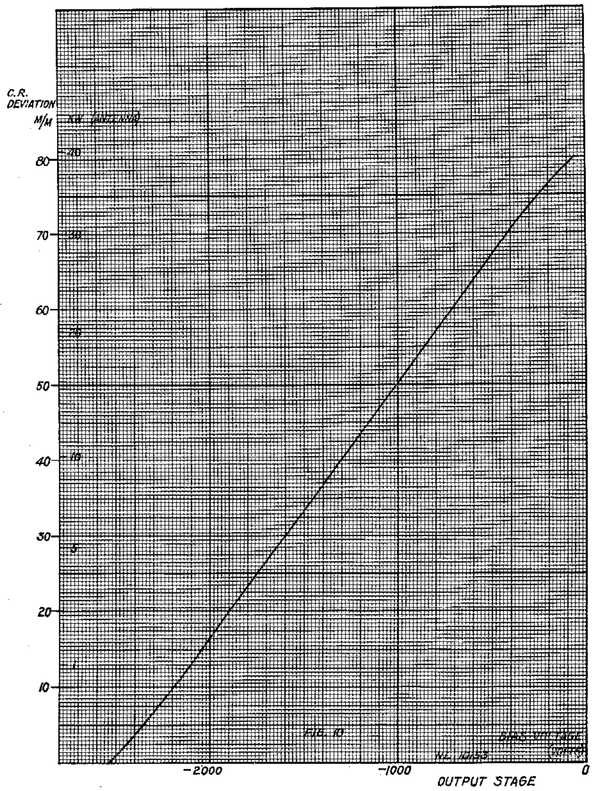


Fig. 10.

Fig. 7b shows the frequency response of the modulator taken between its input and output terminals i.e., between the grid of the modulated amplifier and ground. The output voltage is measured through a calibrated capacity potentiometer. The input level is the same as for Fig. 7a. The zero output level corresponds to the level obtained at 100 kc, about 400 volts rms.

Fig. 7c is obtained by taking the difference between the curve for the complete transmitter and the modulator, and represents the response curve of the output stage alone. It will be seen that this curve is substantially constant, the greater part of the amplitude distortion occurring in the modulator. (The modulator was designed in 1937 for a 2 mc frequency band.)

Fig. 8 gives similar information for phase distortion, indicating the total transmission time between the input of the modulator and the output of the detector coupled to the transmission line. Curve b shows the transmission time for the amplifier alone. The difference between a and b gives curve c, the characteristic of the output stage alone. The difference in the average delay in curves 8a and 8b comes from the fact that additional transmission lines between test instruments were used so that there was a constant difference in the propagation times. In curve 8c the zero level of delay has been placed at the 100 kc value.

Tests were made both at the output of the transmitter and the output of the modulator using the LMT phasemeter with a constant input level of .5 volts rms. This phasemeter measures the angle between two vectors at a frequency of 2000 cycles. A local oscillator is used to beat with the frequency to be measured and adjusted so that the beat frequency is always 2000 cycles. The transmission time is obtained from the angular shift by dividing by the frequency.

The angles may be measured to about one degree so that for transmission times below about .5 microseconds, the accuracy below 100 kc is insufficient. However at these low frequencies direct measurement of the phase angle may be made.

A comparison of curves 8a and 8b shows that the increased delay at high frequencies is largely due to the output stage. It may be stated then that the modulator is largely responsible for the amplitude distortion and the output stage for the phase distortion. This distortion in the output stage is due to the grid reactance and should be compensated in the modulator if it cannot be tolerated.

The curve of Fig. 9 indicates the variation in detected output voltage as a function of input voltage to the modulator. The curve of Fig. 10 is a modulation curve of the output stage, obtained by varying the bias and measuring the output on an oscilloscope coupled to the transmission line. The two curves are substantially straight.

The linearity of the curves at the low-level end is remarkable for a grid-modulated stage. This is due to the quarter-wave line coupling the input to the driver stage.

Measurements of the rms distortion entirely confirm the curves of Figs. 9 and 10 since, for 80 per cent modulation at a frequency of 10 kc, the harmonic content is only 2.1 percent. This distortion does not exceed 3.2 percent at any modulation frequency in the passband.

The Conversion of Buenos Aires City Network to Automatic

By C. G. BARKER, H. E. D. GARNHAM and W. WHITE
United River Plate Telephone Company, Limited, Buenos Aires, Argentina

POLITICALLY, Buenos Aires the world's seventh largest city, is the Federal Capital of the Argentine Republic. With boundaries fixed by law, it is governed by a Mayor appointed by the President of the Nation and an elective Municipal Council. Industrially and commercially, it is the great metropolis, the country's leading seaport, its principal railhead, the distributing center for a vast back-country, the concentration point of most of the business as well as most of the urban population: a cluster of many smaller cities, towns and villages, each independently governed, but all grouped about and dependent for their existence and their development upon the Federal Capital, which is the core of the metropolitan district.

Telephonically, the frontiers which legally confine the Federal Capital insofar as the public administration is concerned do not exist with respect to service. Avellaneda, the largest and most industrial of the suburbs, is separated from the Capital but by a narrow though navigable stream, crossed by many bridges. Other suburbs are literally only just across the street from the Capital.

An 18-year task of converting the system serving the Federal Capital and Avellaneda from manual to automatic working, in the face of rapid growth of the city as a whole and of certain of its areas in particular, of the demand for more ample telephone facilities in all sections, and of a world-wide financial depression followed by war abroad, is drawing to a close. Early in 1942 it is expected that the conversion will be completed, and only dial telephones will exist within the Federal Capital and Avellaneda. It is therefore opportune to review the work that has been done in its chronological sequence, and note the interesting and important facts to be derived from that extensive practical lesson.

To appreciate the complex problem confronting the United River Plate Telephone Co. Ltd., an I. T. & T. subsidiary, it must be borne in mind that when the plan for conversion to automatic was initiated there were only 55,000 stations in the area thus to be converted, whereas at the completion of the task there will be approximately 270,000 stations connected to 25 automatic exchange buildings, as against 16 manual exchanges in 1923. At the same time, a manually operated suburban system has increased from 5,100 stations connected to 22 exchanges in 1923, to 31,000 stations connected to 32 offices in 1941. The expansion of this latter service has constituted a continuous and constantly growing inter-office trunking problem and has added substantially to the volume of traffic flowing in and out of the Federal Capital throughout the conversion period.

The Buenos Aires automatic system serves a thickly built-up urban area of 238 square kilometers with a population of 2,860,000, including the adjacent industrial suburb of Avellaneda previously mentioned. The entire metropolitan telephone area, i.e., the Federal Capital proper and its suburbs, embraces 1,500 square kilometres with a total of 3,750,000 inhabitants. A plan of this area is shown in Fig. 1. This plan shows by a heavy line the separation between the automatic capital network and the manual suburban network. The various classes of service given in each exchange area are indicated as follows:

Automatic in gray, C.B. shaded, Magneto in white and one rural automatic area is cross-hatched. The 10, 20 and 30 km circles are drawn from Cuyo as a center to give an idea of the size of the area. Main trunk routes are shown in full line where underground, and dotted where aerial. Each office area is identified by a two letter abbreviation and the characteristic which is dialed to reach it. Office locations in the network are shown by a small circle; the offices indicated by a small square near the 30 km circle are provincial offices to which toll fees are charged.

The modernization of the Buenos Aires telephone system and its simultaneous expansion to meet annual requirements are of more than local significance, not only because of the importance of the Capital in the life of the nation, but also because it is the concentration point and switching center for most of the national and international long distance service. While these outside services in general function the same regardless of whether the local service in the Capital is manual or automatic, it is, nevertheless, obviously more difficult to convert the local system in a city which is not only the point of origin and destination of the majority of the long distance and international traffic, but which is also the hub of the entire communications network.

Initiation of Automatic and 1924 Study

The conversion of Buenos Aires was commenced by the inauguration of Barracas, Corrales, Retiro and Plaza offices and the transfer of some 6,000 manual subscribers.

On January 1, 1923, the Buenos Aires Capital network, including Avellaneda, contained some 50,000 manual subscribers served from 15 manual exchange areas as indicated by the heavy line boundaries of Fig. 2. It had previously been decided for economic reasons to relieve the existing congested C.B. offices by the addition of automatic step-by-step type offices. This class of office had already been working satisfactorily for

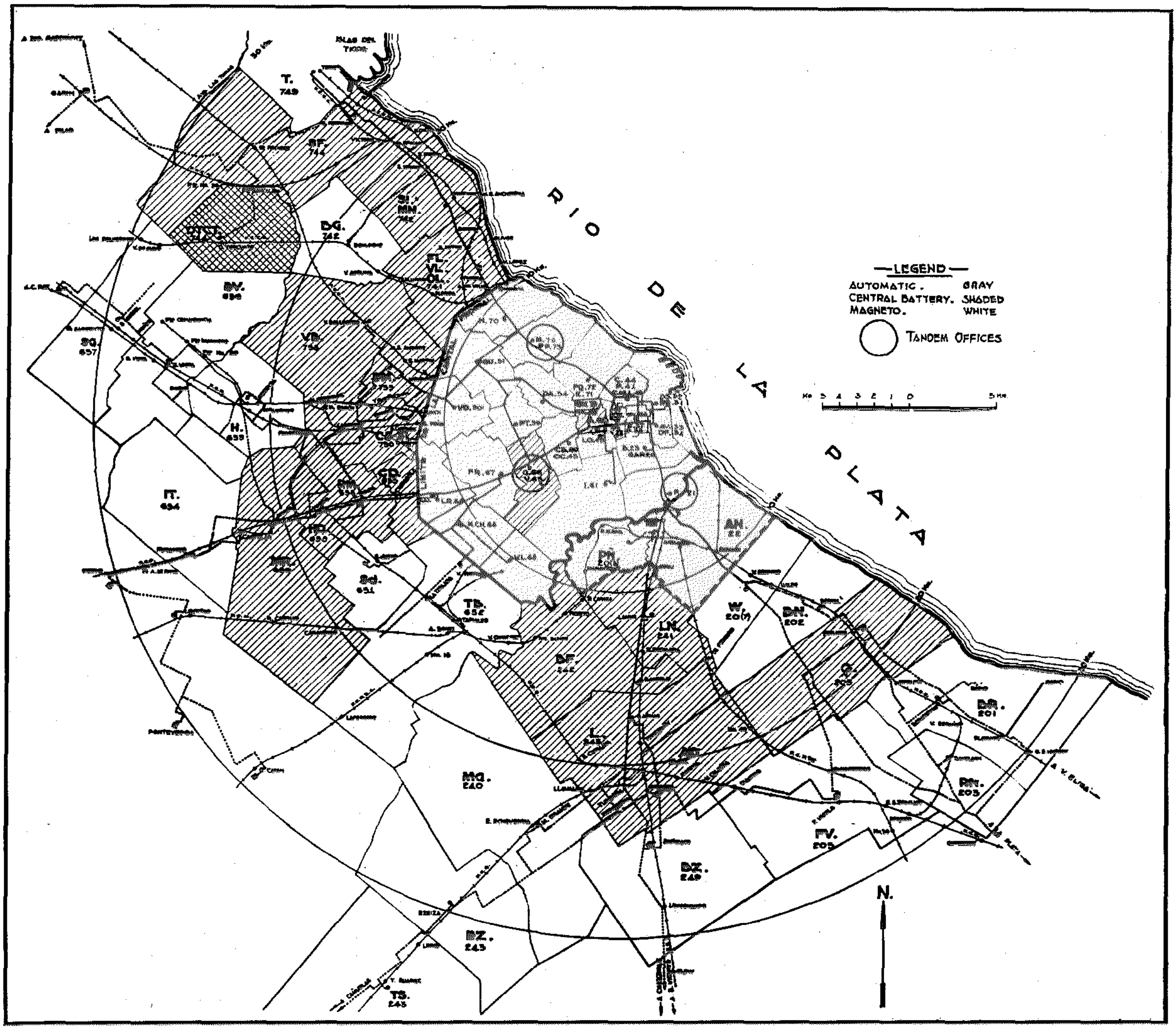


Fig. 1—Fundamental Plan Buenos Aires and Suburbs. Office locations and boundaries, main trunk routes and class of service are indicated.

some ten years in Rosario and Córdoba, two important provincial cities, in connection with which some staff had been trained in automatic working.

A ten-year study was made covering the period up to January 1, 1935, the main purpose of which was to determine the most economical layout for the conversion of the whole Capital to automatic. At this time the Mitre C. B. area was very large and had been growing at the rate of approximately 14 percent per annum during the previous ten years. It had reached its maximum capacity, and studies were made to determine the most economical way to subdivide this large area, resulting in the arrangement indicated in Fig. 2. This plan shows the Capital exchange locations and boundaries at 1923, also those proposed under the new arrangement at 1935.

Economic studies showed that the residue of the Mitre area could be more economically di-

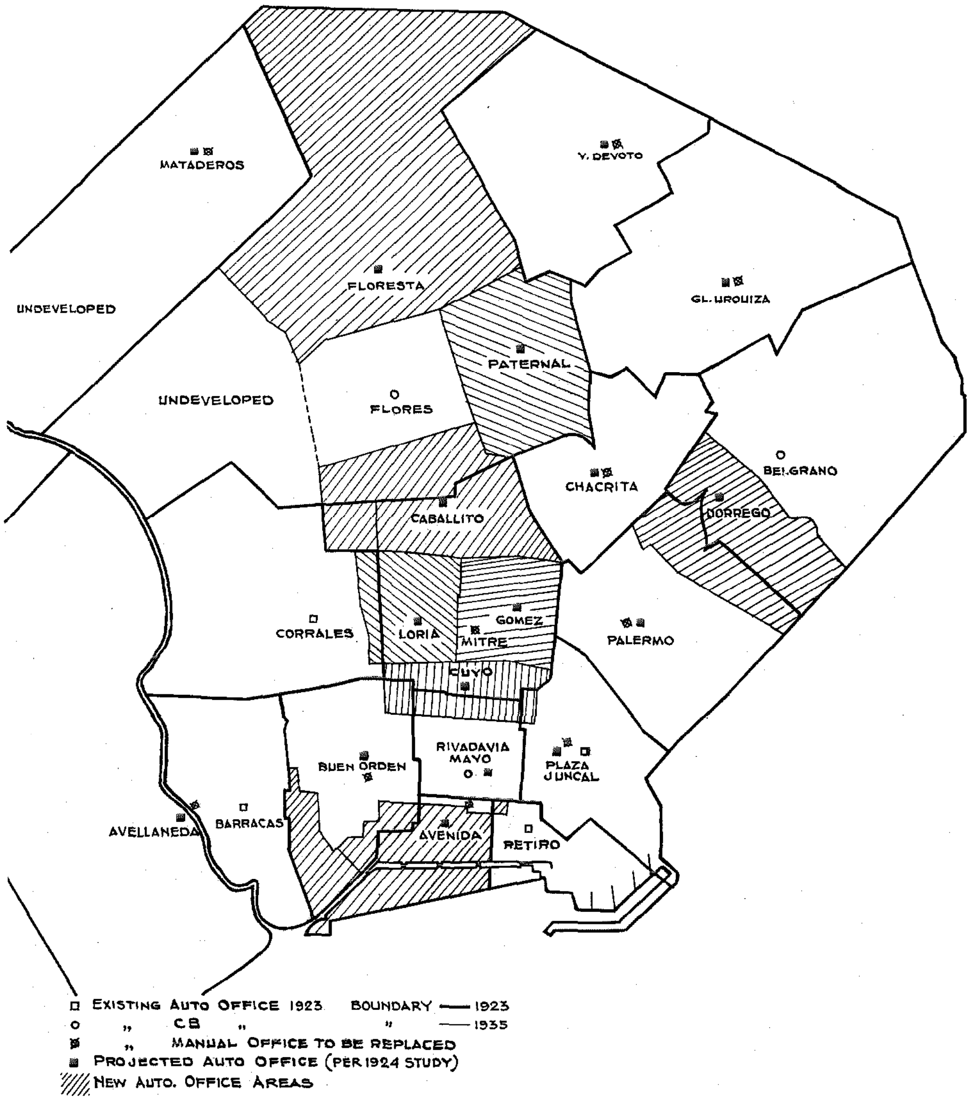

MATADEROS
V. DEVOTO
UNDEVELOPED
FLORESTA
GL. URQUIZA
PATERNAL
UNDEVELOPED
FLORES
CHACRITA
BELGRANO
DORREGO
CABALLITO
CORRALES
LORIA
GOMEZ
MITRE
PALERMO
CUYO
RIVADAVIA
MAYO
BUEN ORDEN
PLAZA
JUNCAL
BARRACAS
AVELLANEDA
AVENIDA
RETIRO
□ EXISTING AUTO OFFICE 1923
○ " CB "
" MANUAL OFFICE TO BE REPLACED
PROJECTED AUTO OFFICE (PER 1924 STUDY)
▨ NEW AUTO. OFFICE AREAS
BOUNDARY —— 1923
" —— 1935

Fig. 2—Fundamental Plan Buenos Aires City Showing Capital Exchange Locations and Boundaries.

vided into two offices, and it was therefore planned to replace the remaining part of Mitre at a later date by Loria to the south and Gómez to the north. In addition to Mitre, several offices did not have sufficient capacity to carry the estimated growth for more than a few years. As a result of districting comparisons, the placing of the following offices in relation to existing offices was recommended:

Cuyo between Rivadavia and Mitre;
Caballito between Mitre and Flores;
Floresta on the far side of Flores;
Paternal between Flores and Urquiza;
Dorrego between Belgrano and Palermo.

The Retiro office had been opened in 1923 as the first step of the division of the Avenida area into two parts and it was proposed to find a site near Plaza Mayo, which was the new telephone center for the modified Avenida area, and place a large building and 20,000 lines of automatic at this site in order to eliminate the existing office in Avenida de Mayo 761, which was structurally unfit to carry automatic loads.

In the case of the Rivadavia-Mayo exchanges, a third unit was planned to be placed in the lot adjoining the Libertad C.B. office. Libertad subscribers were transferred to Mayo and the Libertad building was demolished and a new building erected to house the third automatic unit and engineering offices. The first section of the building on the corner of Rivadavia and Libertad had been rebuilt and was housing the Rivadavia C.B. office. The Mayo automatic office was inaugurated on the second floor of this building in 1924, a few months before the study was started.

In order to relieve Buen Orden, it was recommended to divert part of this area to Avenida and part to Barracas, where a new exchange had been opened, thus permitting the conversion of Buen Orden to be deferred to a later date when other more urgent conversions had been completed.

Belgrano, Flores and Rivadavia were relatively new N°.1 C.B. exchanges and it was therefore planned to retain them as manual exchanges throughout the entire ten-year period covered by the study. The conversion of the Capital was to be 88 percent completed on January 1, 1935. The progress of the conversion compared with the study estimate is shown in Fig. 3, and it will be seen that for the first seven years the estimate was closely realized; but thereafter, due to the economic crisis, the anticipated rate of development and conversion was not maintained, almost all expenditure being limited to projects covering immediate station gain.

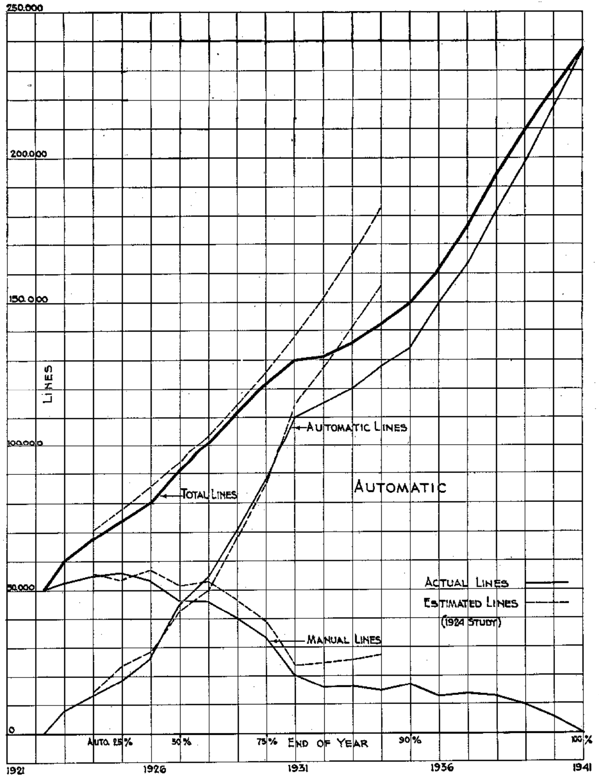


Fig. 3—Conversion of Buenos Aires to Automatic—Proportion of Automatic Lines Each Year.

Transmission conditions were improved by the conversion to automatic, since the Stone 200×200 feed with 48 volt battery gives slightly less loss than the Hayes 24 volt feed with 22×22 ohm repeating coils; and further, the larger areas were being reduced in size, thus shortening the long subscribers' loops. Solid back transmitters were in use at the time the 1924 study was made; after the 323-W. transmitters were introduced about 1929, a new transmission study was made covering both Capital and suburbs.

Modification of Plan

During the years 1925 to 1930, the following modifications were made in the plan:

1) In 1926 an office was opened in Liniers to the north of Floresta where, due to electric traction, paved roads, motor-bus service and a Municipal housing scheme, mushroom growth had developed. The Liniers area before the office was opened in May, 1926, had 86 subscribers, and approximately 1,143 five and a half years later (December, 1931).
2) In 1930 a relief exchange to Belgrano was placed on the north side of the office in Nuñez, instead of on the south side, as shown under "Dorrego" in the original study (Fig. 2).
3) In the same year the conversion of Belgrano and Flores to automatic was started by placing step-by-step equipment in the existing C.B. buildings.

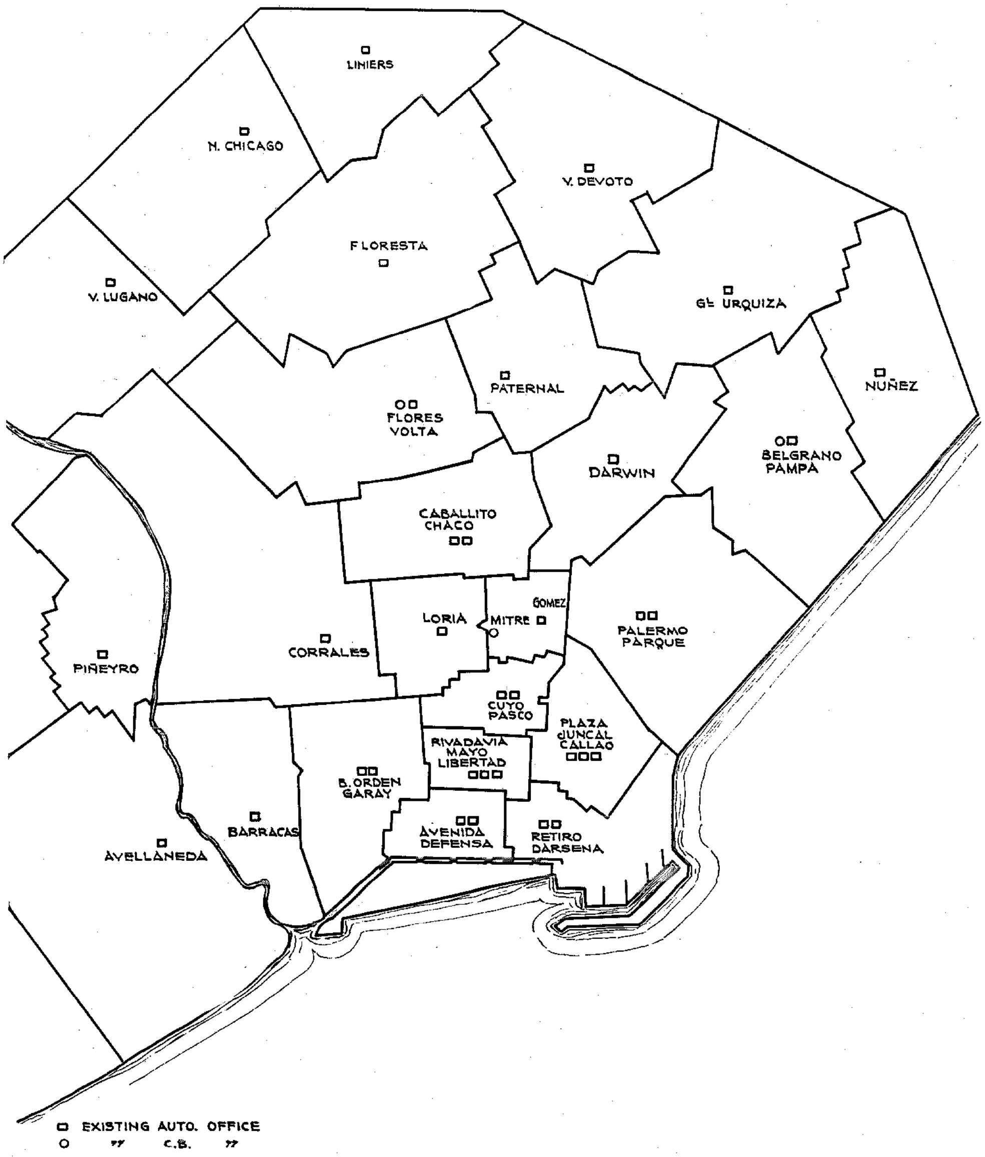

LINIERS
N. CHICAGO
V. DEVOTO
FLORESTA
V. LUGANO
GL URQUIZA
PATERNAL
NUÑEZ
FLORES VOLTA
DARWIN
BELGRANO PAMPA
CABALLITO CHACO
GOMEZ
LORIA
MITRE
PALERMO PARQUE
PIÑEYRO
CORRALES
CUYO PASCO
PLAZA JUNCAL CALLAO
RIVADAVIA MAYO LIBERTAD
B. ORDEN GARAY
BARRACAS
AVENIDA DEFENSA
RETIRO DARSENA
AVELLANEDA
☐ EXISTING AUTO. OFFICE
○ " C.B. "

Fig. 4—Buenos Aires City Network (Early 1942).

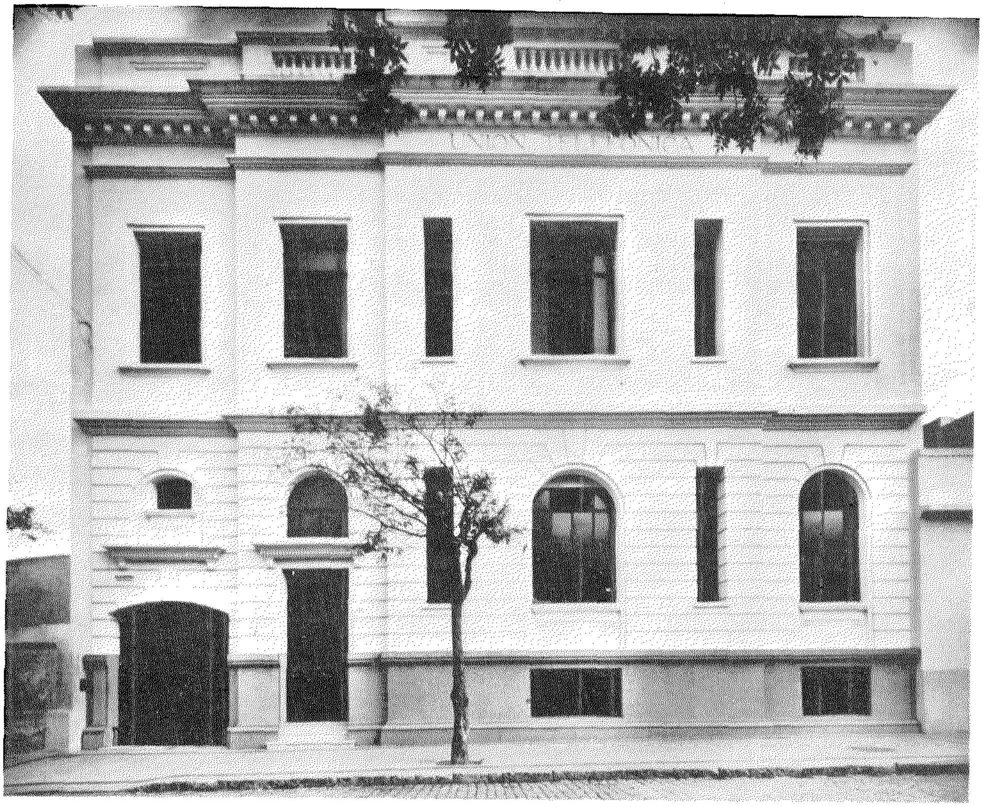


Fig. 5—Gómez Exchange, Buenos Aires.

4) Piñeyro satellite office in Avellaneda was opened in 1936.
5) Villa Lugano satellite office was opened in 1940. The network as it is and will be when the conversion is 100 percent complete is shown in Fig. 4. It will be noticed that it is very similar to that outlined in the original plan shown in Fig. 2.

Progress

In 1927, five new automatic exchanges were opened under the plan at Cuyo, Caballito, Floresta, Avellaneda and Palermo; at the end of that year, 20,000 lines were working in these exchanges, consisting of 15,000 manual lines cut-over and 5,000 new lines added during the year, bringing the percentage of automatic lines in the Capital on December 31, 1927, to 50 percent of the total.

After opening Villa Devoto and the large Defensa Administration building in 1928, and inaugurating the Avenida automatic unit in the latter building in January, 1929, another heavy year occurred in 1930, when six more automatic units were inaugurated, three in existing buildings at Belgrano, Flores and Urquiza, and three in new buildings at Loria, Paternal and Nuñez.

The lines cut-over during 1930 were 12,230, and at the end of the year the conversion was 75 percent completed. Since that date, due to the economic crisis, the conversion was slowed down: Buen Orden was cut-over in 1931, Liniers in 1936, Nueva Chicago in 1937 and Rivadavia in 1939. In 1940, the Gómez building was completed and the new Gómez unit inaugurated. This modern building, shown in Fig. 5, will house some 30,000 lines on two floors; an additional story may be added in the future. This office takes the remaining C.B. lines from Mitre, and also provides relief to surrounding areas. As previously mentioned, it is expected that the conversion will be completed early in 1942.

Numbering Scheme

In 1923 it was anticipated that the number of lines in the Capital would exceed 100,000 in five years, and any initial use of a 5-digit numbering

CAPITAL

200.000 Group		300.000 Group		400.000 Group		500.000 Group		600.000 Group		700.000 Group		800.000 Group		900.000 Group	
Code	Office	Code	Office	Code	Office	Code	Office	Code	Office	Code	Office	Code	Office	Code	Office
20	South East Auto Conc.	30		40		50	V.Devoto	60	Caballito	70	Nuñez	80	Time Service	90	Directory
29		39		49		59	Paternal	69		79	Gomez	89		99	Test Desk
28		38	Mayo	48	Pasco	58		68	N. Chicago V. Lugano	78		88		98	※
27		37	Rivadavia	47	Cuyo	57		67	Floresta	77		87		97	—
26	Garay	36		46		56		66	Flores	76	Belgrano	86		96	Complaints
25		35	Libertad	45	Loria	55		65	Wes Auto.Conc	75	North West Auto. Conc.	85		95	Ring Back
24	South Auto. Conc. Barracas	34	Defensa	44	duncal	54	Darwin	64	Liniers	74	North Auto.Conc	84		94	Repairs
23	B.Orden	33	Avenida	43	Chaco	53		63	Volta	73	Pampa	83		93	—
22	Avellaneda	32	Darsena	42	Callao	52		62	Mitre C.B.	72	Parque	82		92	Toll
21	Barracas	31	Retiro	41	Plaza	51	G.Urquiza	61	Corrales	71	Palermo	81		91	—

※ Co's P.B.X. = 37.911

SUBURBS

SOUTH		SOUTH		WEST		NORTH		NORTH-WEST	
200		240	M.Grande	650	(680 N.C.)	740		750	
209		249	Burzaco	659	Morón	749	Tigre	759	
208	Piñeyro V. Alsina	248		658	R. Mejia Haedo	748		758	V. Ballester
20/7	Wilde	247		657	S. Miguel	747		757	S. Lugares S. Peña Caseros
206		246		656	B. Vista	746		756	
205	F. Varela	245		655	Hurlingham	745		755	S. Martin
204		244	Adrogué	654	Ituzaingo	744	S. Fernando D. Torcuato	754	NOTE
203	Ranelagh Quilmes	243	Ezeiza Lomas Temperley T. Suarez	653	Ciudadela	743		753	
202	Bernal	242	Banfield	652	Tablada	742	S. Isidro Martinez Boulogne	752	
201	Berazategui	241	Lanus	651	Sandusto	741	Florida V. lopez-Olivos	751	

Fig. 6—Buenos Aires Fundamental Plan 6-Digit Numbering Scheme—Characteristic of Each Office Unit, 1941.

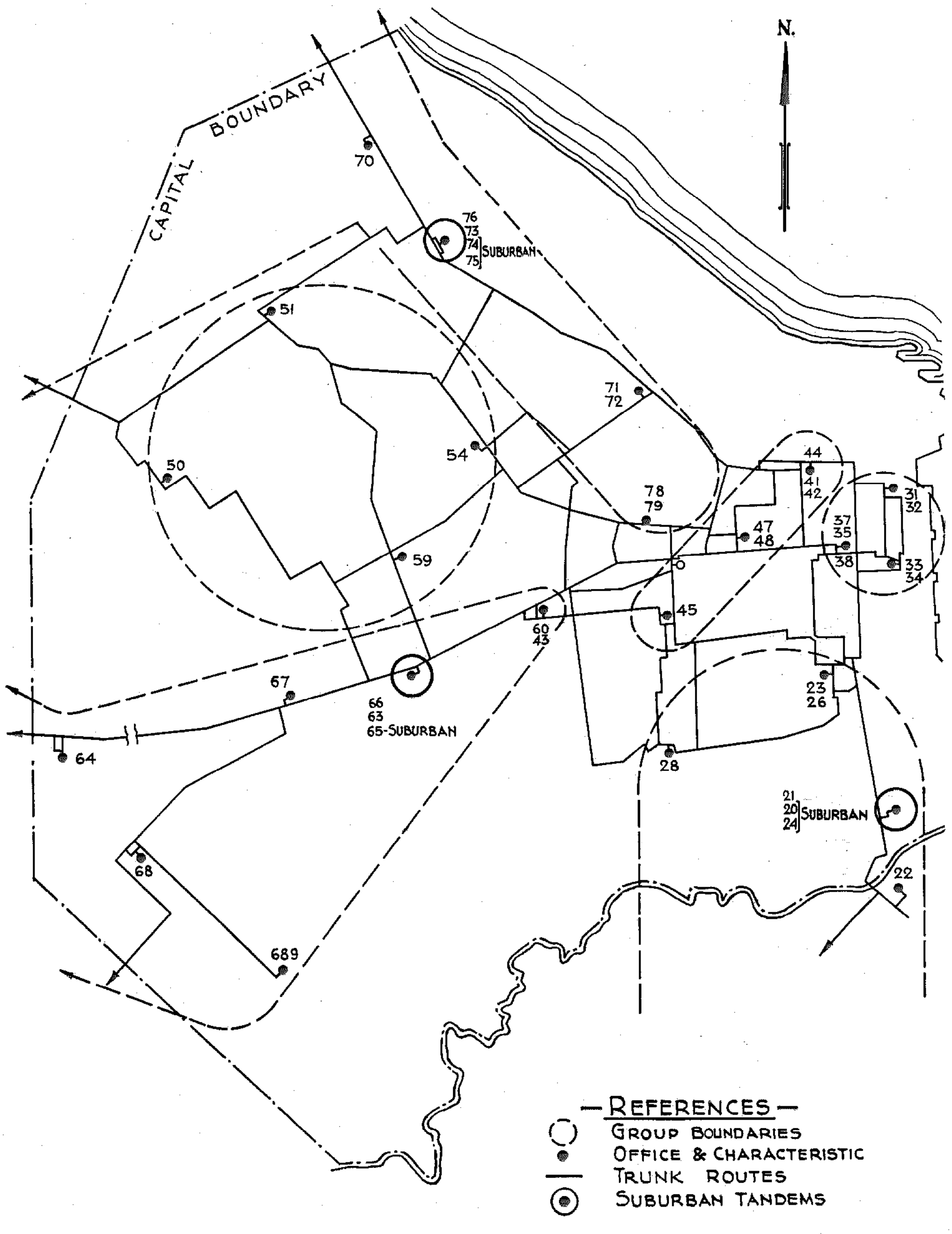

N.
CAPITAL BOUNDARY
70
76
73
74
75
SUBURBAN
51
50
54
71
72
59
78
79
44
41
42
47
48
37
35
31
32
38
33
34
45
60
43
67
66
63
65-SUBURBAN
64
23
26
28
21
20
24
SUBURBAN
22
68
689
— REFERENCES —
GROUP BOUNDARIES
OFFICE & CHARACTERISTIC
TRUNK ROUTES
SUBURBAN TANDEMS

Fig. 7—Numbering Scheme.

scheme was therefore not considered. A 6-figure scheme with 2 digits in the characteristic was adopted, giving a nominal capacity of 800,000 numbers after reserving two levels for Toll and Special Services (Fig. 6). Alphabetical prefixes were not adopted, as with a two letter prefix many names would have had to be altered, thus losing their geographical significance. The initial four offices were numbered 21, 31, 41 and 61 to provide for each office starting with a distinct digit, and also with a view to future grouping for second selector concentration. At the present

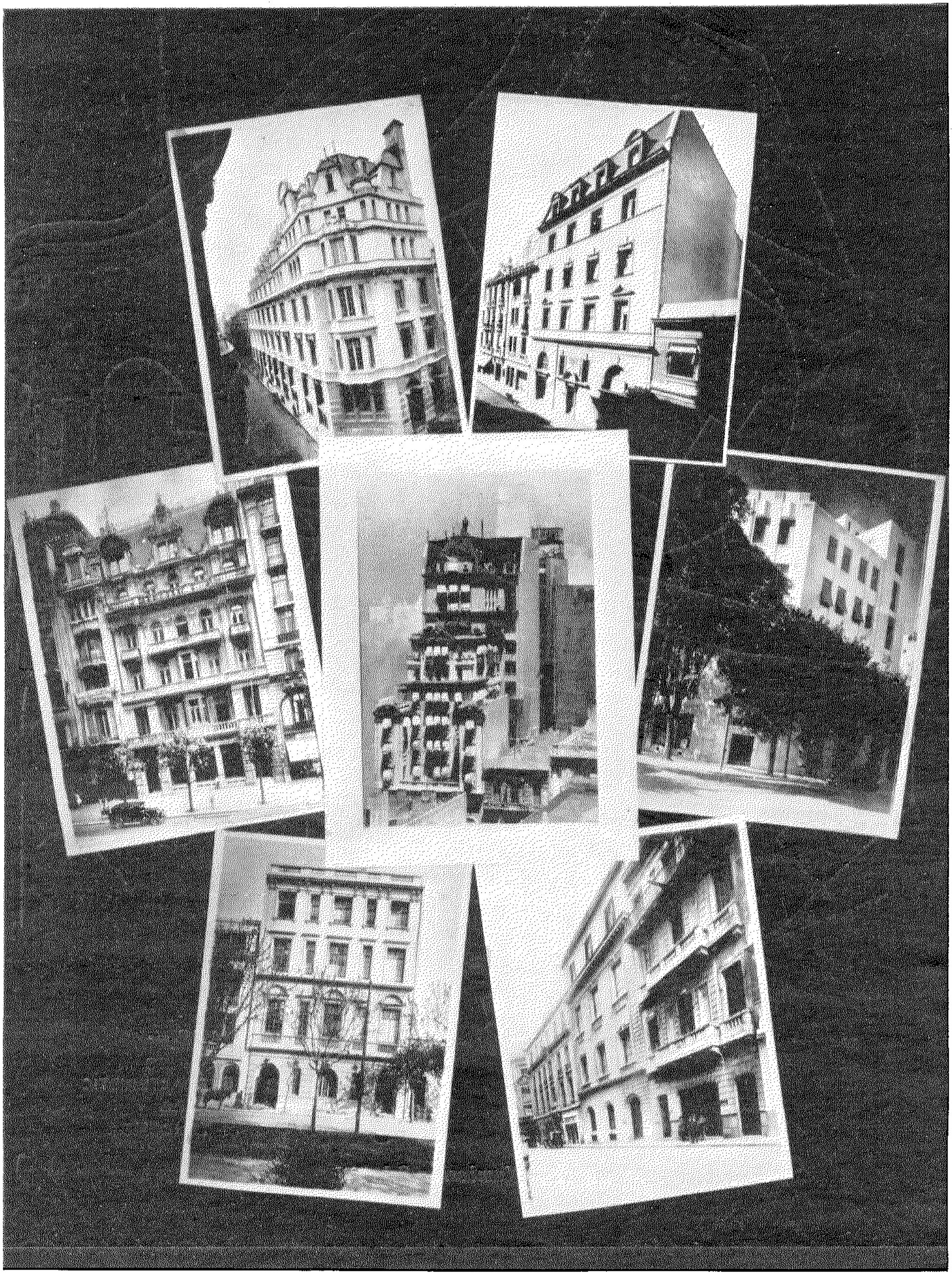


Fig. 8—Seven of the 25 Exchange Buildings of the United River Plate Telephone Company, Limited. In the center is the Administration Building which, in addition to the Executive, Commercial, Accounting and Engineering Offices, houses three Automatic Units.

day this grouping has grown to the proportion shown in Fig. 7. Due to the average length of a Capital trunk being only 3.8 miles and the trunk groups being fairly large, direct trunks are used between Capital offices. The second selectors from which interoffice trunking takes place are 200 point (20 trunk) switches, and for this reason secondary switches are not required for obtaining efficient trunk groups. It has not been found possible to prove-in second selector concentration for Capital trunks, due to the back haul and the cost of extra repeaters where units are not in the same building or close together.

Suburban Tandem

Initially suburban offices were reached by dialing two digits to the tandem operators at Flores (for the West), Belgrano (for the North), and Barracas (for the South). Later considerable economy in operating cost was obtained by placing 3rd selectors in the tandem exchange, the city subscriber dialing a 3 digit characteristic (given in Fig. 6), the 3rd digit extending the call to the local suburban operator. Suburban manual exchanges were equipped with dials to enable the suburban operator to dial direct into 1st and 2nd selectors situated at the automatic tandem points and thence to 3rd selectors in each City office.

Special Services

TOLL AND DSA

In the initial stages monitoring services (96) were attended at special DSA positions in each automatic office and long distance at Cuyo was reached by dialing 92. This involved considerable additional building costs for the extra space required by manual equipment and operators' quarters, and it was later found economical to concentrate toll and special services in four offices: one at Libertad covering the downtown zone and three at the suburban concentration centers for the North, South and West zones. Considerable economy in operating expenses resulted; the postponement of the extension of the toll building at Cuyo was also made practicable.

TIME SERVICE IN BUENOS AIRES

Time service was introduced in Buenos Aires in 1935 in collaboration with the Authorities. To furnish it without adversely affecting the ordinary subscribers' service, arrangements were made to connect to the United River Plate Telephone Co. network a speaking clock supplied and maintained by the Naval Observatory. The City automatic exchanges, divided into three groups, are fed by three duplicate omnibus circuits. Provision has been made, in case of a fault on any part of the line, for switching in the duplicate circuit with a minimum of interruption to the service. The signal receives one stage of amplification at the Observatory and another at the automatic office, where the output is fed to special digit absorbing relay sets to which any subscriber dialing 81 has access. Level 8 was spare so that the cost of second selectors in all offices was avoided. The equipment used was designed by the U.R.P.T. Co. and constructed locally in its workshops; Cía. Standard Electric Argentina installed it.

Buildings

Of the 25 existing buildings housing automatic equipment, nine are one-story, nine two-story and seven multi-story. Records of their cost per square meter of floor space and per line of ultimate capacity indicate that the two-story buildings, as typified by Gómez (Fig. 5), are the most economical. The Administration building, which accommodates the Executive, Commercial, Engineering and Accounting offices, in addition to three automatic units, is shown in the center of Fig. 8. The new six-story extension to the Belgrano building, which houses the Northern Commercial offices, automatic equipment and the Northern Toll and DSA Concentration, appears to the right in Fig. 8.

The 25 plots in the Capital and Avellaneda cover 25,000 square meters, the covered floor space of the buildings totaling 51,000 square meters, of which 36,000 meters are for automatic equipment, equivalent to 0.1 square meters per line of ultimate capacity; the remaining 16,000 meters contain administrative offices, etc. The capacity of the present 25 buildings is 368,000 lines, equivalent to some 420,000 stations.

Due to climatic conditions, the ground floors of Buenos Aires City buildings are usually lofty; this leads to lost space with the low type equipment, but the extra space can now be advantageously occupied with the new high type racks. Air cooling is not used in any office; but air conditioning is included in the specifications for all the newer buildings.

All the older buildings are steel frame and brick. Ferro-concrete has in recent years become a more economical form of construction and is now being used, Gómez being of this type.

Auto Manual Transition Equipment

In order to furnish automatic subscribers entirely mechanical service, insofar as they are concerned, prior to complete conversion, call indicator equipment was installed in the city C.B. offices. A subscriber dialing any city office number thus obtains substantially full automatic service. Automatic calls to the magneto offices Mataderos and Avellaneda were completed over jack-ended trunks on the "B" boards.

Traffic from manual offices and the suburban tandem offices to automatic was completed over keysending or dialing-in positions located in the automatic offices. In general, the traffic from all city manual offices terminated on plug-ended trunks on keysending positions unless the size of the trunk group was too small, in which case jack-ended trunks terminating on dialing-in positions were used.

As the number of automatic offices grew and the provision of further keysending equipment was out of the question, due to the short period of time it would be in use, the "A" Board cord circuits at Rivadavia, Flores and Belgrano were modified for direct dialing; the outgoing trunk multiple was fitted with visual engaged signals and the trunks connected to incoming third selectors in the automatic offices. This modification, and the gradual reduction of the number of necessary keysending positions, facilitated the elimination of a large number of keysending centers and the concentration of keysending at fewer points. In 1936 a new inward toll board was inaugurated and the positions equipped with dialing facilities, so that at the time of writing, keysending is only required for traffic from the Mitre office, the keysending points being located at Mayo and Caballito.

Power Plant Policy

Notable improvements in the type of equipment used have been incorporated in the Buenos Aires City network during approximately the past decade. All power plant has been converted to full float operation; previously, central offices were provided with two sets of batteries, one on charge and the other supplying the office. This method meant a continuous charge and discharge of the office batteries with consequent varying voltage despite end cell switching, or C.E.M.F. cells and relatively short life of expensive batteries.

With the introduction of full float operation the life of the office battery is extended to at least 13 or 15 years of useful life, and the cost of power is reduced inasmuch as the only practical loss of efficiency is in the conversion loss in the motor-generator. Further, manual attendance at the power board is reduced to a minimum, and a smaller battery is required, giving a five-hour busy hour reserve.

To provide for serious failures, two portable Diesel electric units, mounted on trailers, have been provided, either of which is sufficient to supply a complete exchange with power at very short notice. One of these units is capable of furnishing 380/225V, 50 cycle, 3 phase, so that in the event of a failure the office can be supplied with power and lighting. The other unit is equipped with a 24/60 volt d.c. telephone type generator for use in offices where the main supply is d.c., or to supplement the other unit where a multi-unit office is involved. In the long distance office, which also houses two units of automatic equipment, a permanent Diesel 112 HP unit driving a 100 K.V.A. alternator has been installed. This will meet all requirements for power in such an important office, should the necessity arise.

All new offices to be built will be provided with a Diesel electric set for emergency purposes. The size of the office battery can therefore be reduced still further, thereby justifying on a cost basis alone the provision of emergency equipment.

Modifications and Improvements in Equipment

The automatic equipment installed throughout the Capital is of the step-by-step two-motion switch type. The earlier installations used the 25-point rotary line switch for each subscriber,

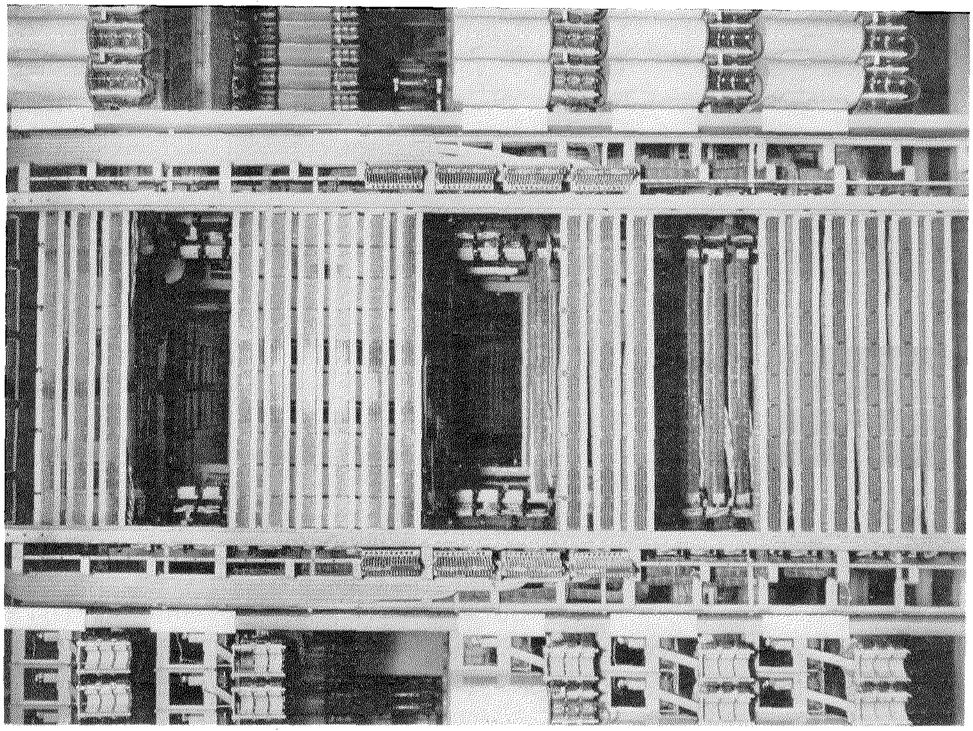


Fig. 9—Automatic Equipment Rack Utilizing Piano Wire Type Assembly.

mounted on line switch units common to this class of step-by-step equipment. From about 1931, the rotary line switch was replaced by the step-by-step two-motion line finder. This change resulted in certain floor space saving and suppressed one additional type of mechanism requiring maintenance, leaving the newer offices with only one class of mechanism. From the outset the 10-level 20-trunk two-motion selector was adopted for reasons discussed under the section on Numbering Scheme. The only exception to its use throughout the network is the Juncal office, which is a 10-group 10-level selector. In this office, however, all the large inter-office trunk groups are routed via secondary line switches of the Keith type with corresponding increased efficiency on these trunk groups.

The offices as originally installed had their selector equipment mounted on the double-sided trunk board usual in step-by-step practice. Commencing about 1931, 11′6″ single-sided type racks were adopted, the design of these racks being practically identical with Bell System practice. The adoption of this high type rack, on which all classes of equipment, including line finders, connectors, group selectors and outgoing relay sets are mounted, has reduced the floor space requirements by some 25 percent.

Owing to building heights, two groupings of the single-sided racks were developed, one 11′6″ in overall height, the other 8′6″.

In order to cater for the 10-level 20-trunk switch, the corresponding terminal assembly had to be especially designed. The original layout of this assembly involved a build-up following the shelf and level segregation principle, in that each level was a complete build-up allowing grading facilities, splitting of shelves, etc., to be done by commoning on pinch type terminals, such build-up being repeated for each of the 10 levels. The later equipment, however, utilizes the piano wire type assembly, illustrated in Fig. 9, and has proved much more flexible from a working point of view than the previous one. This factor is of great importance in this area, owing to the amount of installation movement which takes place.

The line switch unit offices carry an individual I.D.F. mounted upon each unit with cross-connecting facilities between all units. On the adoption of the line finder the standard line I.D.F. was introduced, but in the later offices this has been omitted, the equipment being tightly cabled between M.D.F. line finder rack and final selector rack.

From the foregoing it will be seen that a large number of the older offices contain a very mixed class of equipment, and not the least of the problems has been to combine in an efficient manner these various types of equipment and racks. During one period offices were installed with racks carrying 400 line switches each. Only a few offices, however, contain this equipment which was developed just prior to the adoption of line finder working. The latter principle was adopted since it gave considerable economy over the line switch arrangement, especially in the lower calling rate offices. Line finder working is also used to take care of dead number and out-of-order traffic, such traffic being terminated on the banks of line finders which connect to the special service positions.

Discriminator Offices

A form of satellite working has been adopted for outlying offices and avoids the use of two trunks during a local conversation. This "by-pass" equipment consists of a normal line finder which is searched for over the arcs of a rotary line switch by a discriminator—a two-motion switch which operates in parallel with a distant incoming selector at the main office which received the two first digits dialed. Should the call be other than local, the discriminator releases, leaving the circuit through to the main office and the discriminator available for the next call. In the case of a local call, the discriminator releases the outgoing junction and trunks the circuit through to local selectors, freeing the equipment in the main office. This equipment has proved successful in operation at Nueva Chicago and it is planned to extend its use to future suburban offices where it is justified by the percentage of local traffic and other factors. The Nueva Chicago office serves a large industrial area to the southwest of the city; all trunks, for geographical reasons, have to be routed via the Flores office. It was therefore decided to use by-pass equipment with discriminators for this office and route all traffic via the Western Zone automatic tandem located in the Flores-Volta building. This reduced the number of trunks required in the section Nueva Chicago-Flores since they are combined in one group. From Flores inwards to the Capital exchanges, a large saving in trunks is also obtained by the combination of the Nueva Chicago trunks with the West automatic concentration trunks to each City office.

3-Wire Working

In all cases where more than one unit is located in the same building, as for example Rivadavia-Mayo-Libertad, inter-working between each unit is 3-wire. This method is being extended to adjacent offices where economical, a relay being used in the private wire when necessary.

Protection

The initial installation carried full main frame protective devices; that is, heat coils, arresters and fuses. As the area is almost entirely on an underground basis, it was decided to suppress all main frame fuses. Heat coil and arrester protection on interoffice pairs had been eliminated previously, all such cables being terminated on protector strips with dummy carbons and heat coils to facilitate the use of a test shoe. The present practice is to terminate these underground cables on terminal blocks. In the earlier installations of two offices located in the same building the first and second selectors were common to the two units. It was found, however, that the small economy secured was offset by the additional installation movement and terminal assembly changes required for extensions.

The present policy is to tend to separate the two units completely except from a power plant and main frame viewpoint, or where external trunk groups are small.

Tones

Dial tone was not incorporated in the initial equipment since the use of line switches and the generous provision of first selectors made it inadvisable. With the increase in calling rate and the use of line finders, it was found that the introduction of dial tone would be advantageous and this was inaugurated in 1938 with benefits to both the public and the Telephone Company, the first selectors being reduced in number to give a grade of service of 1 in 100, instead of 1 in 1000, without incurring any noticeable delay. An interrupted busy tone was previously used corresponding to the Spanish word "ocupado." This is now being replaced by a standard 400 cycle busy tone, interrupted twice per second.

Force Adjustment

Two factors of the utmost importance in planning the conversion were even distribution of load on the factory and adjustment of the operating force. Virtually no operators have been laid off during the conversion, the excess personnel having been absorbed by a growth of 24,000 manual lines in the suburbs of Buenos Aires, and by the normal resignations, which average some twenty per month.

Installation

It will be seen from the curve shown in Fig. 3 that the average amount of equipment installed in Buenos Aires has been approximately 15,000 lines per year. This average has been more or less constant except during the 1931/35 crisis years, thus allowing an almost fixed force on installation work to be maintained. The installation of an equal number of lines each year does not cater necessarily for the actual subscribers' relief requirements, and it has been almost a normal procedure to put into service partial relief on large installations, and in some cases inaugurate offices with only a portion of the actual installation completed. Experience shows that the disadvantages of such relief are more than offset by the advantage of maintaining a constant skilled personnel.

Due to the distance at which the installation force was operating from the factory, the close contact which is normal between the Engineering and Installation Departments was difficult to maintain, the installation movement in the offices being of such magnitude that the cable rack and cable engineering had to be carried out on site in some cases. To handle this installation work, an average of one hundred men have been employed in the Capital. This covers the installation of the automatic offices proper, associated trunking equipment throughout the network for the introduction of new offices, general trunking rearrangements due to variations in traffic, and transition equipment for working between automatic and manual. The inauguration of partial reliefs did not allow offices to be routined prior to inauguration over the length of time which is usual in step-by-step installations. It was therefore decided, in order to ensure the correct functioning of the equipment, to readjust all switches completely prior to placing them in service. Considerable time was thus gained since rearrangements could be effected whilst the actual erection was proceeding.

The main advantage of centralized handling of switch adjustment lies in the fact that the work can be done on a mass production basis and semi-expert staff employed to a greater extent than would be the case if the switches were adjusted on site in the individual offices. Centralization also permits closer control of the quality of the equipment and a strict check on the time involved.

During the whole of this transition period, the Argentine supervisory staff has been constantly increased, and the installation force includes many Argentineans. Practically the whole of the equipment installed is of British manufacture, the exception being the Juncal Office which was supplied from the U.S.A. The majority of the British manufactured equipment has been supplied by Standard Telephones & Cables, Ltd., London.

It is interesting to note that even with the long shipment involved, the amount of equipment damaged or lost since September, 1939, has been practically negligible.

Conclusion

The automatic system of Buenos Aires at the date of 100 percent conversion (1942) will consist of 40 offices in 25 buildings with 267,000 lines of equipment installed as follows:—

Offices	Effective line capacity of equip.	Ultimate line capacity of present buildings
40	256,000	368,000

The Buenos Aires automatic area, covering 238 square km, has increased in population, during the years of conversion from manual service, from 1,160,000 inhabitants to 2,860,000. In the same period, the number of telephone stations has increased from 62,000 to 270,000. Thus it will be seen that, in the process of conversion, not only were facilities provided to meet existing demands on the basis of telephone usage at the time the plans were drawn up, but also to take care of an increase from 3.9 percent to 9.5 percent in the station-population ratio.

A New 30 Kw Short Wave Radio Transmitting Equipment for South America

By F. D. WEBSTER and R. E. DOWNING

Federal Telegraph Co., Newark, N. J.

I. *Introduction*

VERSATILITY, flexibility and dependability, attained by the application of many recent significant developments in the art, characterize the 30 kw short wave radio transmitting equipment described in this article.

Versatility is attained by making the equipment capable of operation:

(*a*) On any frequency between 5.7 mc and 22 mc;
(*b*) With crystal control or with self excitation;
(*c*) For CW or MCW telegraphy or by means of a separate modulator for telephone or broadcast;
(*d*) To deliver 1 kw or 30 kw of radio frequency power on telegraphy or 9 kw on telephony or broadcast;
(*e*) Into a balanced transmission line of 600 ohms surge impedance with any standing wave ratio up to two to one.

Flexibility is achieved by construction of the equipment in four mechanically separate units and by the provision of controls which permit rapid and convenient transfer to any type of operation. The four units comprise an R.F. driver, a power amplifier, a 3000-volt rectifier and a 10,000-volt rectifier. For telephone operation two more units are required, namely, a speech amplifier and a modulator. It is planned to add these two units at a later date; consequently, the present description covers only the radio frequency equipment and its associated power equipment.

Dependability is insured by the design of each component so that it will reliably meet the electrical and mechanical operating field conditions. Protective features include special provisions for safeguarding both personnel and equipment.

Voltage breakdown, which is an ever-present hazard due to the high voltages produced in radio

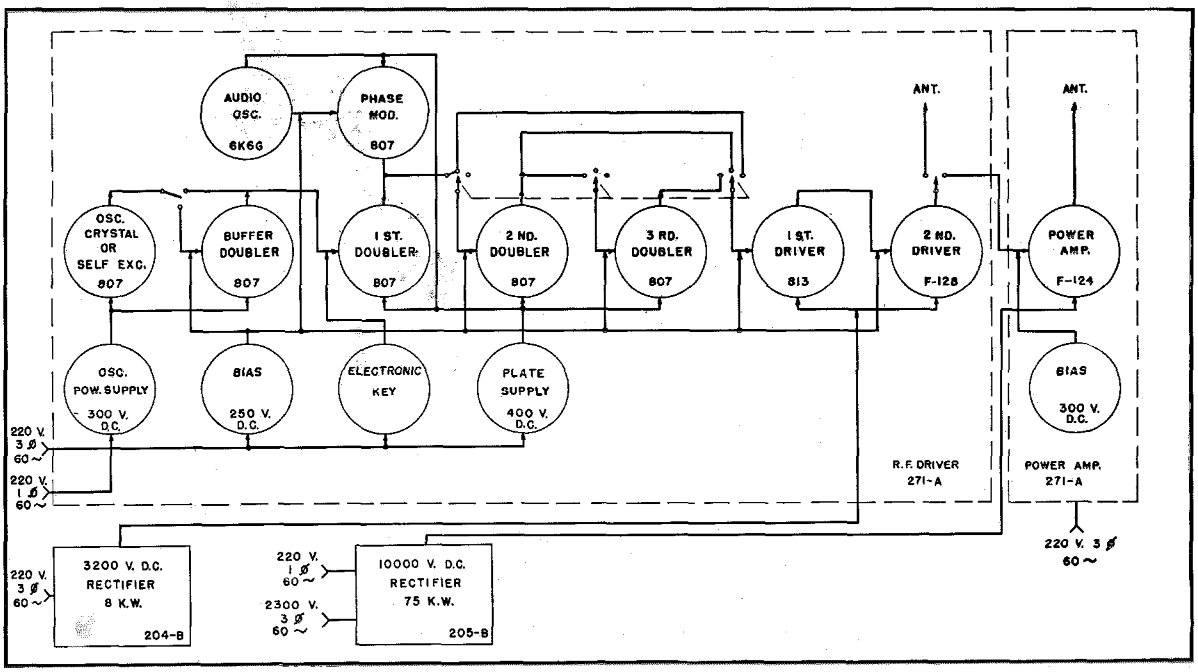

AUDIO OSC. 6K6G
PHASE MOD. 807
ANT.
ANT.
OSC. CRYSTAL OR SELF EXC. 807
BUFFER DOUBLER 807
1 ST. DOUBLER 807
2 ND. DOUBLER 807
3 RD. DOUBLER 807
1 ST. DRIVER 813
2 ND. DRIVER F-128
POWER AMP. F-124
OSC. POW. SUPPLY 300 V. D.C.
BIAS 250 V. D.C.
ELECTRONIC KEY
PLATE SUPPLY 400 V. D.C.
BIAS 300 V. D.C.
220 V. 3 Ø 60 ~
220 V. 1 Ø 60 ~
R.F. DRIVER 271-A
POWER AMP. 271-A
220 V. 3 Ø 60 ~
220 V. 3 Ø 60 ~
3200 V. D.C. RECTIFIER 8 K.W. 204-B
220 V. 1 Ø 60 ~
2300 V. 3 Ø 60 ~
10000 V. D.C. RECTIFIER 75 K.W. 205-B

Fig. 1—Functional Schematic of 30 kw Radio Transmitter.

equipment of this power, is minimized by adequately spacing and insulating all components, by avoiding sharp edges on metal parts, and by installing corona shields and horn gaps where applicable. Excessive temperatures are avoided by employing such means as adequate current-carrying capacity in all conductors, ample radiating surfaces, water cooling, and forced air circulation by means of blowers.

Recent developments incorporated in this equipment include:

(*a*) Electronic keying with weight control;
(*b*) MCW telegraphy by phase modulation;
(*c*) Special type balancing network;
(*d*) Multi-strand filament tube;
(*e*) Vacuum condensers.

II. *Electrical Design*

1. GENERAL

The functional electrical design of the complete equipment is illustrated schematically in Fig. 1; it shows the tube line-up and the function of each stage. The R.F. driver unit (Fig. 2) supplies radio frequency power: continuously for telephony or, when keyed with or without tone modulation, for telegraphy. It requires an external 3000-volt d-c plate power supply in addition to the power supplies included in the unit. This requirement is met by the 3000-volt three-phase mercury vapor rectifier (Fig. 3). These two units supply excitation to the power amplifier or, when used alone, form a complete 1 kw radio transmitter. The power amplifier (Fig. 4) amplifies the driver output to 30 kw for telegraph operation and is capable of modulation for telephony or broadcast to deliver 9 kw output. It requires an external source of d-c plate power which is provided by the 10,000-volt mercury vapor rectifier (Fig. 5).

2. CONTROLS

Each unit of the transmitter is equipped with controls for starting and stopping that unit. The keying circuit permits the transmitter to be keyed from the power amplifier, from the driver or remotely. It may be locked in the key-down position by means of a switch on the driver unit. The 3000-volt plate voltage can be applied to the driver by push-button stations on the power amplifier or on the 3000-volt rectifier. A plate supply control on the power amplifier prevents that unit from being connected simultaneously to more than one 10,000-volt rectifier.

3. PERSONNEL PROTECTION

The problem of personnel protection associated with high voltage equipment has been given considerable attention. The following precautions have been taken in the various units:

(*a*) *10,000-Volt Rectifier*

The 10,000-volt rectifier is completely enclosed with no exposed high voltage components. Parts

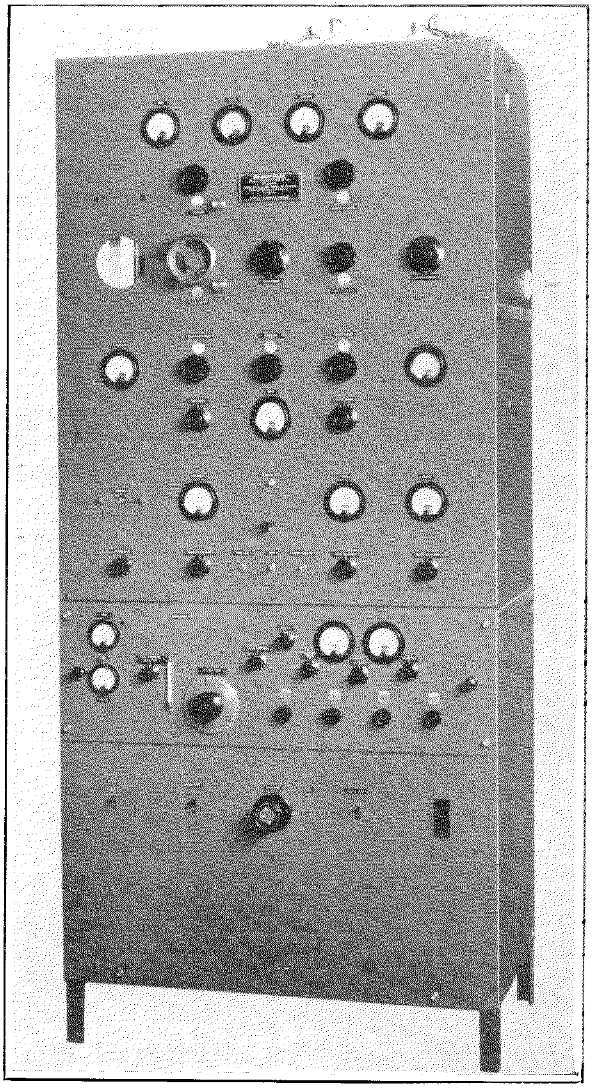


Fig. 2—Front View of R.F. Driver Unit.

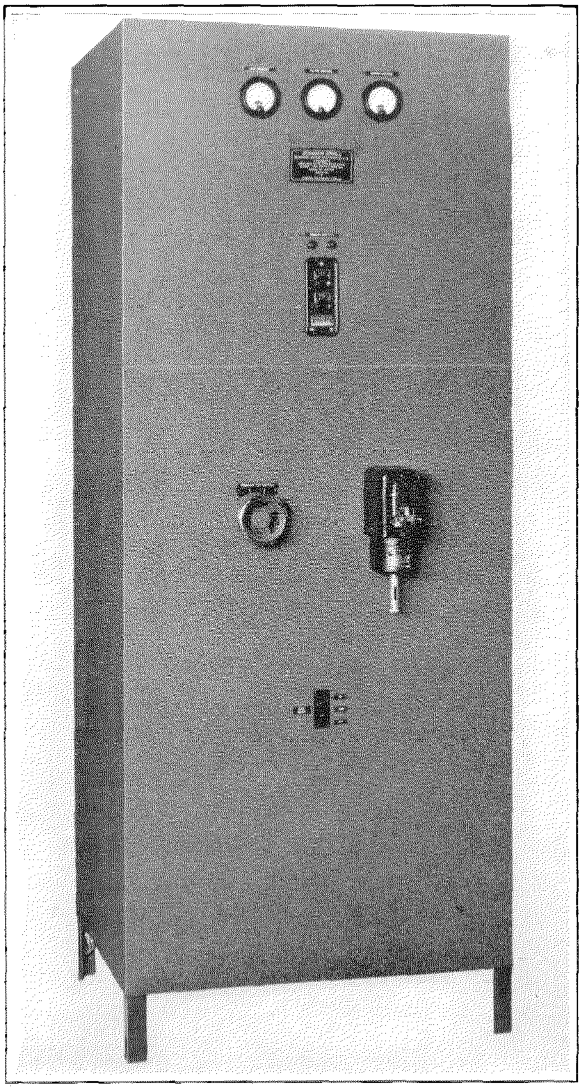


Fig. 3—Front View of 3000-Volt Rectifier.

such as high voltage plate transformer terminals, which might be reached by small objects through the screening, are protected by fixed baffles. Both access doors have electrical interlocks which open the main circuit breaker upon opening the door. In addition, the doors are fitted with mechanical grounding devices which short the high voltage system to ground when the doors are open. An additional manually operated grounding switch is supplied on the front panel which opens the main circuit breaker and grounds the high voltage. The 2300-volt three-phase incoming power lines terminate in an additional enclosure within the main enclosure and are arranged to be inaccessible.

(*b*) *3000-Volt Rectifier*

An electrical door interlock of the "pull-apart", variety and a grounding contactor perform the functions of removing the supply voltage and grounding the 3000-volt d-c output upon opening the access doors.

(*c*) *Driver Unit*

Protective devices similar to those on the 3000-volt rectifier cut the supply to that rectifier and ground the 3000 volts in the driver unit when opening the access doors.

(*d*) *Power Amplifier*

Dual door interlocks are provided on each access door of the power amplifier unit. In order to turn the door latch, it is first necessary to push a button which operates a high voltage oil switch

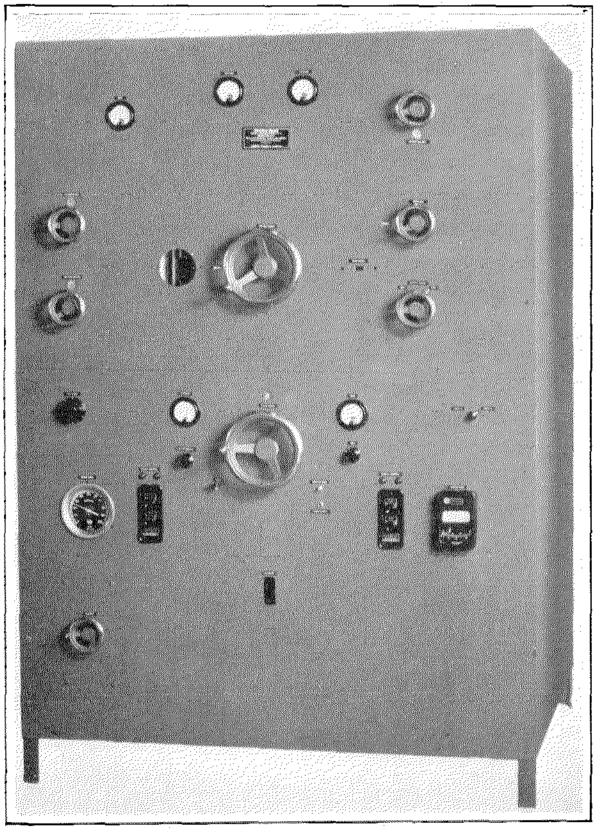


Fig. 4—Front View of Power Amplifier Unit.

located in the main rectifier to remove the voltage from the 10,000 volt line feeding the power amplifier in question. Opening the door causes the pull-apart interlock switch to remove the bias and to operate a contactor to ground the high voltage supply bus within the power amplifier. This arrangement of opening the d-c line to the power amplifier is used rather than opening the main oil circuit breaker of the rectifier because the rectifier may be used to supply two power amplifiers simultaneously. The scheme permits de-energization of one power amplifier without affecting the operation of the other while at the same time providing good personnel protection.

4. R.F. Driver Unit

(a) General

The R.F. driver unit includes in one metal cabinet, the oscillator, buffer-doubler, three doubler and two driver stages together with the phase modulator and all power supplies except the plate supply for the two driver stages. The oscillator covers a frequency range of 980 to 1460 kilocycles when self-excited and 1960 to 2920 kilocycles when crystal controlled. Selection of any one of six crystals or self-excited operation on any one of four frequency ranges is provided by a single switch. The buffer-doubler stage operates as a frequency doubler and isolates the oscillator from the first doubler stage which is keyed and modulated. It is used only for self-excited operation and is disconnected for crystal operation by means of a switch. Another switch is provided whereby one, two or three doubler stages may be connected in the circuit, the number of stages chosen depending upon the desired output frequency. The output of the doubler stages is applied to the first driver stage which employs a beam type power amplifier tube. This in turn excites the final driver stage. The output of the final stage may be supplied to the power amplifier or, through an Alford network (a special type balancing network), to an antenna.

(b) Frequency Control (See Fig. 6)

The oscillator is installed in a constant temperature oven. The oscillator and the thermostatically controlled oven heater each have an individual power switch; both switches are connected to the power mains by a circuit which is independent of the rest of the equipment. The arrangement permits either the oven or the oscillator or both to be continuously energized or to be energized sufficiently in advance of the operation of the rest of the equipment to allow the temperature to stabilize. The oscillator filament and plate voltages are maintained constant within 1 percent independently of line voltage fluctuations between 170 and 250 volts. This is accomplished by an automatic voltage regulator which employs the properties of a magnetically saturated iron core and a partially resonated circuit. In this way, the principal causes of oscillator frequency deviations are eliminated.

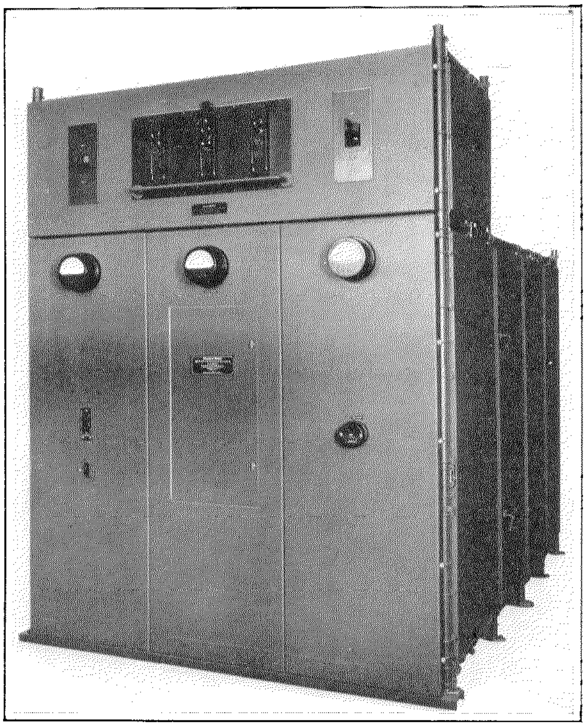


Fig. 5—Front View of 10,000-Volt Rectifier.

(c) Oscillator Temperature Control

Whereas a high degree of temperature control would not be required with the low temperature coefficient crystals employed, a rather close control of temperature of the electric oscillator components is considered desirable. Therefore, a device has been included with the oscillator oven which may be adjusted to compensate for heat leakage which may take place despite the dual insulation used about the oven. It consists of a heat conducting vane with a part of its surface outside the oven and thus exposed to ambient temperature. The portion of the vane inside the oven is in close proximity to the thermostat. The whole assembly is arranged to be adjustable so that more or less heat, as desired, may be transferred from the vicinity of the thermostat to the outside, thus permitting maintenance of the temperature inside the oven within close limits. The inner oven is lined with heavy metal to provide great heat inertia so that fluctuations in temperature of the outer oven, where the heaters and thermostat are located, will not be transferred to the inner oven, or at least will be greatly retarded. Thus, if falling ambient temperature depresses the inner oven temperature, the vane is moved nearer to the thermostat to withdraw heat faster from the thermostat; this causes the latter to be closed a greater proportion of the time, thereby raising the average temperature of the outer oven and maintaining the desired temperature of the inner oven.

The temperature of the inner oven thus is held within close limits without requiring a thermostat so sensitive as to need an auxiliary relay system to handle the heater circuits.

(*d*) *Keying*

On-off keying of the transmitter is employed for both CW and MCW telegraph operation; it is accomplished by applying to the control grid of the first doubler stage, when the key is open, fixed bias sufficient to block the tube. When the key is closed the bias is reduced to the normal operating value. The key controls the grid bias of the doubler stage through an electronic keying circuit which includes a weight control. The weight control allows the relative duration of marking and spacing pulses for dots to be adjusted. A filter is inserted between the electronic keyer and the doubler grid circuit to shape the telegraph characters and minimize key clicks. A monitor consisting of a diode rectifier electrostatically coupled to the R.F. output is provided so that, by connecting an oscilloscope to its output, the shape of the telegraph characters can

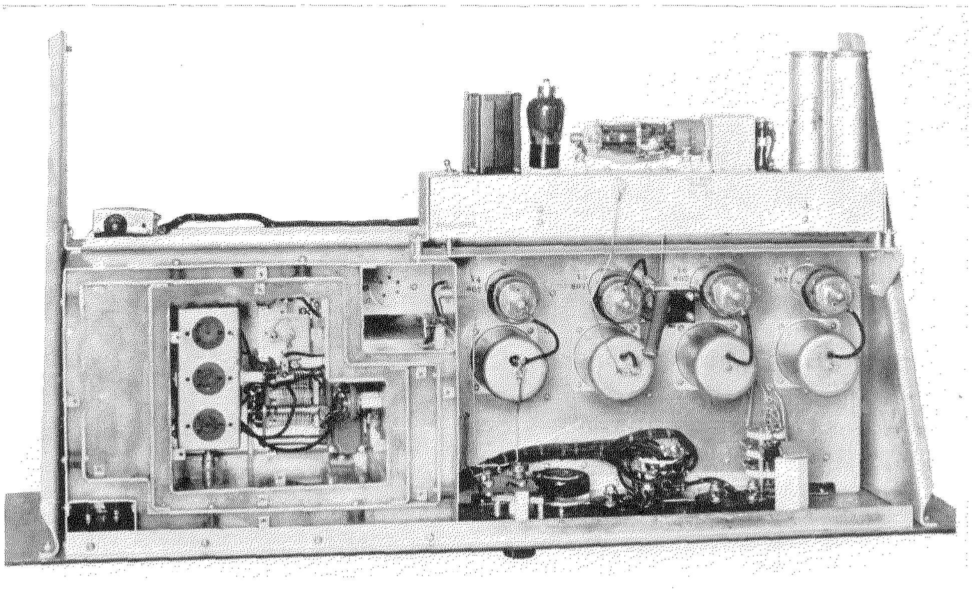


Fig. 6—Top View of Oscillator-Multiplier Tray.

be observed. The keying circuit allows the transmitter to be keyed at any speed up to 400 words per minute.

(*e*) *Phase Modulation* (*See Fig. 6*)

Tone modulation for MCW telegraphy is obtained by phase modulation which is indistinguishable from frequency modulation when a single constant modulating frequency is used. It has the advantage over the latter of not affecting the carrier frequency and thus eliminates the necessity for special frequency control circuits. This type of modulation was adopted in preference to amplitude modulation because it produces a distinctive signal that is more easily read through interference and, in addition, it generates multiple sidebands which contribute to reduction of selective fading. Further, it accomplishes these results with a minimum of equipment and power consumption.

(*f*) *Lange Neutralizing Circuit* (*See Fig. 7*)

The R.F. driver unit output stage employs an air-cooled triode (Type F-128-A) operating as a neutralized power amplifier. It embodies the Lange neutralizing circuit which accomplishes neutralization by a principle entirely different from other commonly used circuits; with the tube grid-plate capacitance, it forms an unsymmetrical bridged T network. The series element connected to the grid is a tapped inductance, the series element connected to the plate is a fixed condenser and the shunt element which connects to ground is a variable condenser. One of the advantages of this circuit is that any two elements may have any desired value. When these two values have been chosen, the value of the third element is fixed by the relation for neutralization. The arrangement used in this equipment has been found highly convenient. In this case, the plate neutralizing condenser is fixed and has a capacity approximately equal to the tube grid-plate capacity. The grid neutralizing condenser is variable with an average capacity about four times that of the plate neutralizing condenser. The inductance is tapped at such intervals as to permit neutralization within the range of the variable condenser over the complete range of frequencies. Neutralization is obtained by adjustment of the variable condenser.

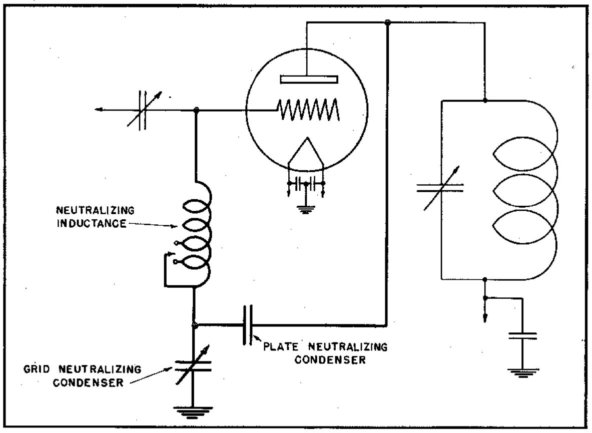


Fig. 7—Lange Neutralizing Circuit.

(*g*) *Output Circuit* (*See Fig. 8*)

The output circuit of the R.F. driver unit consists of two tuned circuits inductively coupled. Five adjustments are provided, thereby allowing the most effective condition to be obtained for any load or frequency. This type of output circuit also effectively reduces harmonics.

A switch is provided in order that the R.F. driver output may be connected either to the power amplifier or to an antenna through a balanced transmission line. Although the output stage uses a single ended circuit, a balanced output is provided suitable for feeding a two-wire transmission line by employing a special type balancing network. The latter consists of two identical tapped inductances and a variable condenser connected in star. The condenser leg connects to ground and the two inductance legs connect to the two sides of the transmission line. One transmission line conductor connects to the high potential side of the driver output stage. The network is balanced for only one frequency so that for each frequency the proper tap on the inductances must be selected and the variable condenser adjusted until no parallel currents flow into the output circuit, a condition which is approximately achieved when the two R.F. meters in the transmission line indicate equal currents.

(*h*) *Antenna Meters*

The antenna is fed from the transmitter through a two-wire transmission line for which two terminals are included in the driver unit.

These terminals are connected to the output of the special type balancing network by heavy conductors. Electromagnetically coupled to each of these conductors by means of a small shielded and grounded loop of wire is a thermocouple. The thermocouples supply the two R.F. ammeters located on the front panel of the R.F. driver unit. The coupling between the conductor and the loop is adjustable and is set to give a correct indication of transmission line current at that point. This arrangement prevents the antenna meters from being damaged by lightning.

5. Power Amplifier Unit

(a) *Vacuum Tube with Multi-strand Filament*

The power amplifier unit employs a water-cooled triode with a six-strand filament (Type F-124-A) in a neutralized amplifier circuit. The tube requires a total filament power of 5.6 kw at 27.2 volts, representing 206 amperes in a single-strand filament and 68.7 amperes per strand in a six-strand filament connected three-phase. The six-strand filament thus permits the use of conductors and terminals in the filament circuit of a more convenient size. An additional advantage is that the filament may be supplied from a three-phase source resulting in a reduction in hum modulation from the filament. Filament starting current surges are limited by high reactance filament transformers. The rated filament voltage is obtained for various line voltages by a three-phase continuously adjustable auto-transformer.

(b) *Filament By-Pass Condenser (See Fig. 9)*

Parasitic oscillations are frequently present on the filament leads of high power tubes if the filament is not by-passed to ground for radio frequencies at the filament terminals. For this reason, each filament strand is by-passed to ground at the tube terminals by an assembly of mica condensers of original design. The connection to each tube filament terminal is made by a clamp with a large hexagonal head screw. Each clamp is attached to a circular plate provided with holes to pass the clamps for the other terminals. The six plates are stacked vertically with a grounded plate at each end and between each of the other plates. All the plates are separated by sheets of mica. The grounded plates are connected to the tube cap by a clip and to ground by a short heavy strap. The terminal clamps are located so that the assembly fits over the tube terminals and is supported on them. The filament supply leads are flexible stranded conductors and are attached to the same condenser plates as the corresponding clamps but to the opposite surface by means of special terminals. This condenser unit is compact and convenient to attach to the tube. The use of hexagonal head screws on the clamps renders practicable the removal of the assembly when it is at operating temperature by loosening the screws with a wrench.

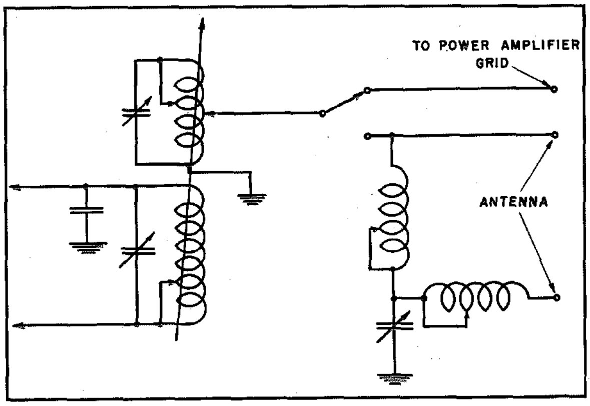


Fig. 8—Driver Output Circuit.

(c) *Vacuum Condenser*

This stage employs the Lange neutralizing circuit previously described. The fixed condenser in the branch to the plate comprises four vacuum condensers in a series parallel connection, giving a capacity approximately equal to the tube grid-plate capacity. At the high voltages involved in this unit (18,000 volts), the vacuum condensers represent a large saving in space over an equivalent fixed air condenser.

(d) *Bias Supply*

Included in the power amplifier unit is a 450-volt fixed bias supply which biases the tube to cut-off when the R.F. drive is removed. Under normal operation, the tube employs grid leak bias and the fixed bias is made ineffective for all grid leak bias voltages larger than that of the fixed bias by connecting the fixed bias supply in parallel with the grid leak bias through a pair of high vacuum rectifier tubes. These two rectifier

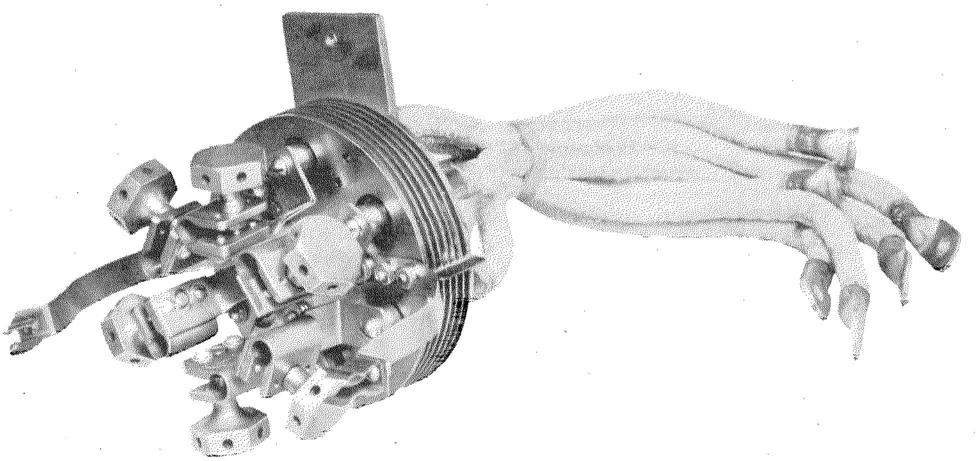


Fig. 9—Filament By-Pass Condenser.

tubes are connected in parallel and prevent the grid current from flowing in the fixed bias supply. The amount of grid leak bias must be greater for telephone operation than for telegraph. The grid leak resistor has the proper value for telephone operation but with a section short circuited by the normally closed contact of a relay to give the correct resistance for telegraphy. For telephone operation, the relay is energized and removes the short circuit.

(e) *Water Cooling System*

The power amplifier water cooling system is designed for connection to the water mains and requires 16 gallons per minute at 45 pounds per square inch pressure. The water system cools both the tube and the plate tank inductance. Loss of radio frequency power in the water system is minimized by the use of porcelain water coils. A contact-making flow meter is included which causes the unit to be shut down whenever the water flow drops below a safe amount. It is also arranged so that if the filament power is applied before the water is turned on a warning signal is given. Further, an outflowing water temperature indicator is provided which causes the power to be removed if the water temperature becomes excessive. A part of the circulating water is caused to flow through the copper tubing of the main plate tank inductance to provide cooling for the coil.

(*f*) *Plate and Output Circuits* (*See Fig. 10*)

The plate tank inductance is a "rams horn" type coil; that is, it consists of two equal sections connected in parallel and wound in opposite directions along a common axis so that their fields reinforce each other. Water is supplied to this coil through a porcelain insulating water coil and enters the tank coil at each end of the "rams horn," exhausting at the center into the side of the tube water jacket. Power is taken from the plate circuit by a coupling coil, which is likewise in two sections connected in parallel and wound so that the two sections are aiding. A section is located at each end of the plate inductance. This type of coil construction provides increased mutual inductance which is especially advantageous at the higher frequencies where only a small portion of the total inductance is in use. The output coupling coil is tuned by a variable condenser which may be connected either in series or parallel; selection is made by a special switch fitted with an interlock which removes the plate voltage before a change can be made. This feature adds to the convenience of adjusting the transmitter and facilitates obtaining the optimum adjustment under various operating conditions.

Changes in tuning ranges are effected by short circuiting the proper number of turns of each coil, shorting bars of various lengths being supplied for this purpose. These bars are fastened to the coil by screws with large hexagonal heads for which a special wrench is provided so that the frequency can be changed even when the coils are at operating temperature.

Air condensers have proved more satisfactory than mica condensers for plate by-pass in high frequency and high power transmitters. For this reason, the plate by-pass condenser is a three-plate fixed air condenser incorporating a frame partition as one plate.

The plate tank tuning condenser and the output coupling condenser are both individually shielded. The shielding not only makes the circuits less critical to adjust at the higher frequencies but equalizes the voltages on the condensers thereby minimizing possible flashovers due to misadjustments or standing waves on the condenser frames.

The output coupling circuit connects to a special type balancing network which, except in size, is identical with the one in the R.F. driver unit. The use of two tuned and inductively coupled circuits reduces harmonic radiation.

6. 3000-Volt Rectifier Unit

The 3000-volt rectifier unit is rated at 8 kw and supplies d-c voltages of 3300, 3000, 2800 and 2200 volts. The rating of this unit is much larger than the power requirement of an R.F. driver unit so that capacity is available for supplying two driver units and two modulators simultaneously if desired. It is energized from the 220-volt, 60 cycle, three-phase mains. Six type F-353-A mercury vapor tubes in a three-phase full-wave rectifier circuit are utilized.

Any one of the above mentioned d-c voltages is obtained by turning a handwheel located on the front panel. This handwheel actuates tap switches on the three-phase plate transformer; they connect to taps on the primary windings. It also actuates an interlock switch to open the primary oil circuit breaker and to remove voltage from the transformer before the taps are changed. Voltages of one-half the normal voltages can be obtained by operating the unit as a half-wave three-phase rectifier. A terminal is provided for this purpose, connecting to the neutral point of the wye-connected plate transformer secondaries. One-half voltage operation will be used only when the R.F. driver is modulated for telephony or broadcast.

Filament voltages are held constant under line voltage fluctuations by an automatic voltage regulator of the saturated core type.

Tube temperatures are maintained within proper operating limits by a blower operating into a duct which distributes the cooling air to each tube.

7. 10,000-Volt Rectifier Unit

The 10,000-volt rectifier is a self-contained unit rated at 75 kw and is adequate for supplying a power amplifier and modulator or two power

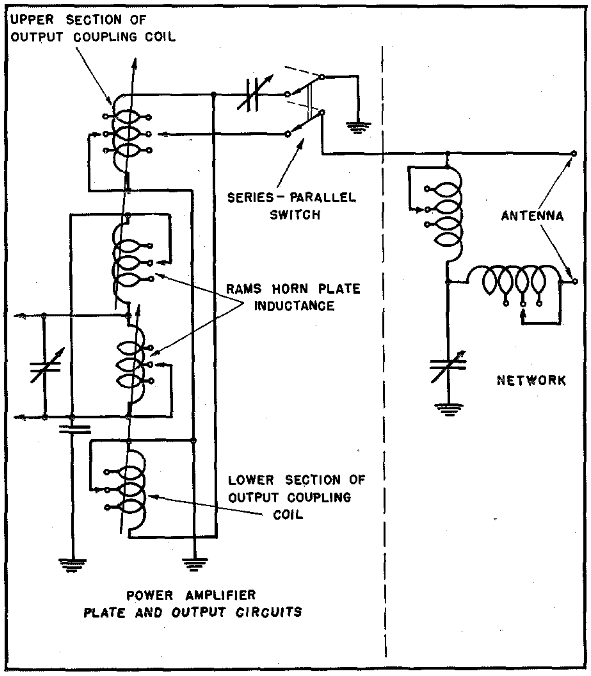

UPPER SECTION OF OUTPUT COUPLING COIL
SERIES-PARALLEL SWITCH
RAMS HORN PLATE INDUCTANCE
LOWER SECTION OF OUTPUT COUPLING COIL
POWER AMPLIFIER PLATE AND OUTPUT CIRCUITS
ANTENNA
NETWORK

Fig. 10—Power Amplifier Plate and Output Circuits.

amplifiers. It employs six type F-369-A mercury vapor tubes in a three-phase full-wave rectifier circuit. By replacing these tubes with type F-357-A tubes its rating can be increased to 110 kw. The d-c output voltage is adjustable in five steps, namely, 10,000, 9750, 7500, 6300, and 5000 volts, by primary taps on the plate transformers controlled by a handwheel with which an interlock switch is associated to disconnect the power whenever the taps are changed. Two power supply sources are required: (1) 220 volt, 60 cycle single-phase for the filaments and control circuits; (2) 2300 volt, 60 cycle, three-phase for the plate circuit. The filament voltage is stabilized by automatic voltage regulators which also limit current surges occurring when voltage is applied to the filaments. Tube temperatures are controlled by air cooling provided by a blower working into a duct system.

Plate power is applied to the rectifier through a primary oil circuit breaker equipped with undervoltage, a-c over-current and d-c over-current protection. D-C voltage is supplied to one or both of two power amplifiers through oil switches which can be closed electrically only at push-button stations on the respective power amplifiers. They can be opened or closed manually at the rectifier and are opened automatically when the rectifier plate power is disconnected.

When plate voltage is applied to a mercury vapor rectifier, the filter condenser offers a very low impedance to the transient so that a current surge occurs which frequently damages the tubes in the absence of preventive measures. In this unit, a charging resistor is connected in series with the filter condensers; a relay with normally open contacts operates to short circuit this resistor 1/25 second after the plate voltage is applied.

Puncture of the filter reactor insulation by overvoltages set up by keying or switching transients is prevented by thyrite disks connected between the reactor output terminal and ground. The reactor is connected in the low potential or negative lead to minimize voltage strain on its insulation; it is also protected by a sphere gap.

8. SPECIFICATIONS

The following table of specifications summarizes the foregoing equipment description:

Service: CW radio telegraphy; MCW radio telegraphy; capable of telephone and broadcast operation.

Frequency Range: 5700–22,000 kc. Six pre-set frequencies. Change can be made between any two pre-set frequencies in less than five minutes.

Power Output: 30 kw telegraphy; 9 kw telephone or broadcast.

Frequency Control:

Crystal: ± 0.01% of specified frequency. Temperature coefficient less than 2 parts per million per degree Centigrade.

Self-Excited: Output frequency can be set within 0.5% of any frequency. Output frequency remains within 0.01% of the original frequency during any period of 15 minutes continuous operation. Output frequency remains within 0.1% of the original frequency during a period of 12 hours continuous operation.

Output Circuits: On any multiple of the carrier frequency, the harmonic output is at least 45 db below the carrier. The output circuit is designed for two-wire connection to the antenna. The transmitter is capable of delivering its rated output at any frequency between 5700 and 22,000 kc into a two-wire transmission line of 600 ohms surge impedance and with possible standing wave ratios of 2 to 1. Into this line the transmitter provides an output balanced on the two wires.

Reduced Power Output: The transmitter is so arranged that the final amplifier and main high voltage rectifier can be removed from the circuit and the transmitter operated with a power output of 1 kw. Output terminals, coupling circuits and a special switch are provided for this purpose on the next to the last amplifier stage.

Filament Voltages: No vacuum tube operates with a filament voltage in excess of the value recommended by the tube manufacturer for normal tube life.

The equipment is arranged to apply automatically full filament and plate voltages with the time delays recommended by the tube manufacturer. During the starting sequence, the filament current in no tube with directly heated filament and plate dissipation in excess of 100 watts exceeds 175% of the filament current of the same tube when completely heated.

Controls are provided for adjusting and indicating the filament voltage of all tubes except the oscillator which is regulated automatically.

Power Supply: The transmitter requires a 2300-volt and a 220-volt supply, both three-phase 60 cycle.

Telegraph Keying: The transmitter keys satisfactorily up to 400 WPM. The output during spacing intervals is essentially zero. Electronic keying is used and is provided with a control on the front of the transmitter for controlling the weight of the keyed characters, i.e., changing the percentage marking and spacing on dots.

Monitoring Facilities: The following monitoring facilities are provided, each of which produces an output of at least 10 volts rms:

1. Rectified output of the whole transmitter to permit oscilloscope observation of keyed characters or modulation wave-form.
2. Same as (1) for the driver unit.

III. ***Mechanical Construction***

(*a*) GENERAL

The complete equipment for telegraph operation is supplied in four mechanically independent units. These four units are:

R.F. Driver
Power Amplifier
3000-Volt Rectifier
10,000-Volt Rectifier

The R.F. driver unit and the power amplifier unit must be bolted together with the power amplifier at the right when viewed from the front. This is necessary in order to allow short direct radio frequency connection between these two units and to equalize the R.F. voltages induced in the two frames. The remaining units may be located as desired.

The R.F. driver, power amplifier and 3000-volt rectifier are each built around a frame of steel angle members with the required shelves and partitions for mounting and shielding the various components. The frames are totally enclosed with rear doors for access. The 10,000-volt rectifier is built around a pipe frame enclosed with panels on front and sides and with a grille on the rear. All the units are uniformly finished with gray wrinkle enamel.

(*b*) R.F. DRIVER UNIT

The R.F. driver unit is 82 inches high, 36 inches wide and 24½ inches deep. All controls are on the front panel except the taps on the output coupling coil and the taps on the special type balancing network inductances which are accessible by doors on the rear. These doors are perforated for cooling and backed with screening to prevent the entrance of insects. Power and control circuit connections are made to terminals at the lower rear. The antenna connection is made to two terminals on the top; the power amplifier is connected through an insulating bushing on the upper right side panel.

The frame is divided by shelves into four compartments. The bottom compartment houses the blower and the power equipment. The next compartment is constructed like a filing cabinet drawer and can be readily removed; it contains the oscillator, buffer, doublers and phase modulator. Directly above is the first driver stage compartment. The top compartment houses the final driver stage and the output circuits.

(*c*) POWER AMPLIFIER UNIT

The power amplifier unit is 82 inches high, 55½ inches wide and 40 inches deep. It is divided into four completely shielded compartments. The two top compartments house the filament transformers and the special type balancing network. The lower left compartment contains the grid circuit components including the bias voltage rectifier. The remaining compartment contains the type F-124-A tube, its plate circuit components and the output coupling circuit components. Rear accessibility is provided by four doors which cover the entire rear area of the frame. A door on the left side gives added accessibility to the grid compartment.

All controls are on the front panel except the adjustment for the plate, coupling, and network inductances which are adjusted from the rear by opening the doors. All connections except R.F. are made at the lower rear of the unit. Two terminals on the top provide connection to the antenna. An opening in the upper left side opposite the bushing on the R.F. driver unit is provided through which the lead supplying the R.F. power for driving the unit is passed.

(*d*) 3000-VOLT RECTIFIER UNIT

The 3000-volt rectifier is mounted in a frame 51 inches high, 32 inches wide and 25 inches deep. Its construction is similar to that of the two radio frequency units. All controls are on the front panel and rear accessibility is provided by doors.

(*e*) 10,000-VOLT RECTIFIER UNIT

The 10,000-volt rectifier unit is 114 inches high, 89 inches wide and 114 inches deep. All controls are on the front panel except the tap changing handwheel which may be located on either side panel at the rear. A door in the center of each side opens on a passageway which extends across the unit. This passageway divides the rectifier into a front and a rear section. The rear section contains the transformers, filter components, and tubes while the front section contains the metering and control equipment. The top and bottom of the frame are left open. All equipment, such as transformers which are not attached to the frame, are mounted on the floor within the enclosure.

One installation, as herein described, has been purchased by All America Cables and Radio Inc. for use in the expansion of its International service at Lima, Peru.

Recent Telecommunications Developments

AVIATION RADIO.—The Civil Aeronautics Administration carried out a series of field tests on various types of aural four-course U.H.F. radio ranges at Indianapolis, Indiana, and Van Nuys, California. These tests indicated that radical changes were necessary in the antenna system for the ranges. The design for these improved antennas was based upon developments by the International Telephone & Radio Manufacturing Corporation, and during 1941 eight of the improved radio ranges were installed in the New York–Chicago airway. This airway is now under test but indications are very definite that the four-course aural range will be superseded by the two-course range noted below.

An ultra-high frequency two-course visual radio range with aural quadrant identification was developed by the engineers of I.T. & R.M. for the C.A.A. during 1941. This important new aid to air navigation was demonstrated on October 30, 1941 at the Indianapolis Municipal Airport to members of the radio range subcommittee of the Radio Technical Commission for Aeronautics. After extensive flight tests, participated in by airline pilots, the range received unanimous approval. It is quite likely that this type of radio range will be adopted for the civil airways of the U.S.A. and that several hundred will be installed throughout the country.

The Federal Telegraph Company, a unit of the International Telephone & Radio Manufacturing Corporation, is in process of completing the manufacture of a fourth order of simultaneous long wave radio range stations for the C.A.A. More than 70 percent of the total number of these range stations in use in the U.S.A. are of the Federal Telegraph type.

U.H.F. Marker Antenna Systems have been the subject of some development work and improvement, and C.A.A. engineers, recently, set up and tested at Indianapolis, Ind., an improved type of Z marker antenna system. Radiation from this type of marker is sharper than from previously used types and is substantially free from secondary lobes.

The Civil Aeronautics Administration has awarded the Federal Telegraph Company a contract for the manufacture of ten instrument landing system equipments intended for installation at principal U.S.A. airports. This contract is in addition to one previously recorded in this journal for systems, now in process of installation, at La Guardia Field and other airports.[1]

This instrument landing system,[2] permits fliers to land entirely by instruments. Many fliers already have been trained in its use, and these installations are intended to familiarize all commercial airline pilots throughout the country with its operation as a vital additional safeguard against sudden bad weather.

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NEW ARGENTINE BROADCASTING CHAIN.—Red Argentina De Emisoras Splendid (RADES) has contracted with Compañía Standard Electric Argentina, Buenos Aires, a subsidiary of the International Standard Electric Corporation, for eight medium wave broadcasting stations. LR4 (Radio Splendid), Buenos Aires, will be powered at 50 kw; LW1 (Radio Cultura), Cordoba, and LT2 (Radio Stentor), Rosario, at 20 kw; LU3 (Radio Del Sur), Bahia Blanca, and LV6 (Radio Mendoza), Mendoza City, at 10 kw; and LT4 (Radio Misiones), Posadas, LU5 (Radio Neuquen), Neuquen City, and LW7 (Radio Catamarca) Catamarca City, at 1,500 watts. Radio Splendid (LR4), similar to station LS1 of the Municipality of Buenos Aires,[3] will incorporate the high efficiency Doherty Amplifier.

These stations are planned to provide coverage for the entire Argentine Republic as well as contiguous areas in sister republics. Facilities for interconnection to outlying stations will include a 25 kw short wave transmitter, which will relay programs from the Buenos Aires station (LR4) and which also will be constructed by C.S.E.A.

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[1] *El. Com.*, Vol. 19, No. 3, p. 5, 1941.

[2] "Development of the C.A.A. Instrument Landing System at Indianapolis, by W. E. Jackson, A. Alford, P. F. Byrne, and H. B. Fischer, *El. Com.*, Vol. 18, No. 4, 1940.

[3] "Broadcasting Station LSI–Buenos Aires," by R. E. Coram, A. W. Kishpaugh, and W. H. Capen, *El. Com.*, Vol. 17, No. 1, 1938.

Broadcast program circuits of the United River Plate Telephone Company, Limited, in certain cases, will be utilized for interconnection purposes.

This is the first time that any South American firm has undertaken the production and installation of a complete chain of broadcasting stations on the scale projected. The contract also is the largest single one for broadcasting stations ever awarded in South America.

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COLUMBIA BROADCASTING SYSTEM'S NEW SHORT WAVE TRANSMITTERS WCRC AND WCBX.—Following closely on the placing in service of the 50 kw Broadcasting Station WABC, C.B.S., on January 1, 1942, inaugurated two short wave transmitters for international broadcasting. These also were designed and built by the Federal Telegraph Company, a unit of the International Telephone & Radio Manufacturing Company. To accommodate the short wave transmitters, the Mackay Radio and Telegraph Company constructed an addition to its main transmitting station at Brentwood, Long Island, New York.

The transmitters consist of three driver units and associated power amplifiers of 50 kw carrier power output capable of 100 percent modulation. Two modulator units and power supplies are provided to permit simultaneous operation of two transmitters while the third power amplifier is lined up for immediate program switching to another high frequency band. Special features not previously employed in similar transmitters include line type tank circuits and an ingenious antenna switching arrangement which permits connecting any transmitter to any of the numerous antennas.

For use with these transmitters Mackay Radio designed and constructed thirteen high gain antennas directed on Europe, Central and South America. Three of the antennas are reversible so that they can be used at different hours to northern Europe and to Mexico and Central America. In anticipation of future developments, the antenna insulation and provisions for avoiding corona are in excess of anything previously constructed in the short wave field in the U.S.A.

MACKAY RADIO AND TELEGRAPH COMPANY.—The Company has improved and extended its ultra-high frequency radio circuits used as keying and tone lines between central offices and the transmitting and receiving stations. The circuits include transmitters working in the 156 and 160 megacycle band modulated by as many as sixteen separate tone channels. Very effective high gain directive antennas were developed for use on these circuits. Among interesting features, the antennas embody provision for reducing the effects of ice or sleet accumulations. Circuits of this type now in service are as follows:

New York to Brentwood (New York): 40 miles, 16 channels

Brentwood to Southampton (New York): 45 miles, 3 channels

Southampton to Brentwood (New York): 45 miles, 9 channels

San Francisco to Palo Alto (California): 28 miles, 16 channels.

An 85-mile circuit between Southampton and New York with intermediate relay at Brentwood is in experimental operation, and circuits in both directions between Southampton and Amagansett, 18 miles, are under construction.

Mackay Radio from New York, recently inaugurated direct radiotelegraph service to Foynes, Eire, Moscow, U.S.S.R., and La Paz, Bolivia; also a circuit between San Francisco and Khabarovsk, U.S.S.R. Tests are being conducted between Honolulu, Hawaiian Islands, and Chungking, China, and between San Francisco and Wellington, N. Z., involving circuits which it is planned to open shortly for regular traffic. It added new equipment to its coastal station at Jupiter, Florida, to provide improved service to ships in the South American and Caribbean trade, making this station the most powerful in the Southeastern region of the U.S.A. Its fourth marine service station was opened in the region of the Gulf of Mexico at Mobile, Alabama.

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TOLL PLANT ADDITIONS IN THE STATES OF RIO GRANDE DO SUL AND PARANA, BRAZIL.—In 1939 Companhia Telephonica Rio Grandense began construction of a main toll route from Porto Alegre west to Santa Maria in the State of Rio Grande do Sul. Since that time extensions have been carried out from Santa Maria to the cities of Cruz Alta, Ijui, Santo Ângelo, São Pedro, São Gabriel, Don Pedrito and Bage.

During 1941 toll construction was continued between Sao Gabriel and Rosario, a distance of about 64 kilometers. This construction represents a further step in the extension of toll facilities to the western part of the state looking towards eventual land line connection with Argentina. It is anticipated also that the São Gabriel–Rosario construction will be completed early in 1942 and that it will be extended to Livramento on the Uruguayan border, a distance of about 109 km. When completed, international connection will be established with Uruguay through Rivera, situated opposite Livramento.

The Companhia Telefonica Paranaense in 1941 extended the Curityba-Castro portion of its main toll route into the northern part of the State of Parana by the completion of the Castro–Santo Antonio da Platina section, a distance of about 39 km. This is part of a proposed 240 km extension to connect the rich northern agricultural part of the state with the capital city of Curityba. On completion, this project will be the means of connecting the Company's network with certain other important Brazilian cities.

INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION

Associate Companies in the Western Hemisphere

UNITED STATES OF AMERICA

International Standard Electric Corporation: *Manufacturer and Supplier of Communication and Other Electrical Equipment Through Licensee Companies Throughout the World; Exporter of Communication and Other Electrical Equipment*.....New York, N. Y.

International Telephone & Radio Manufacturing Corporation: *Manufacturer of Communication and Other Electrical Equipment*.......East Newark, N. J.

Federal Telegraph Company: *Manufacturer of Radio Equipment*..........................Newark, N. J.

Commercial Cable Company: *Trans-Atlantic Telegraph Service*.....................New York, N. Y.

Commercial Pacific Cable Company: *Trans-Pacific Telegraph Service*.................New York, N. Y.

Mackay Radio and Telegraph Company: *International, Domestic and Marine Radio Telegraph Services*
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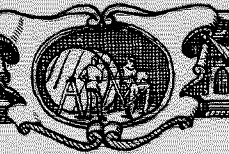

ELECTRICAL COMMUNICATION

Technical Journal of the
INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION
and Associate Companies

1942

VOL. 20 No. 4

ELECTRICAL COMMUNICATION

Technical Journal of the
INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION
and Associate Companies

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Published Quarterly by the

International Standard Electric Corporation

67 BROAD STREET, NEW YORK, N.Y., U.S.A.

H. M. Pease, President C. D. Hilles, Jr., Secretary

Subscription, $3.00 per year; single copies, 75 cents

Volume XX 1942 Number 4

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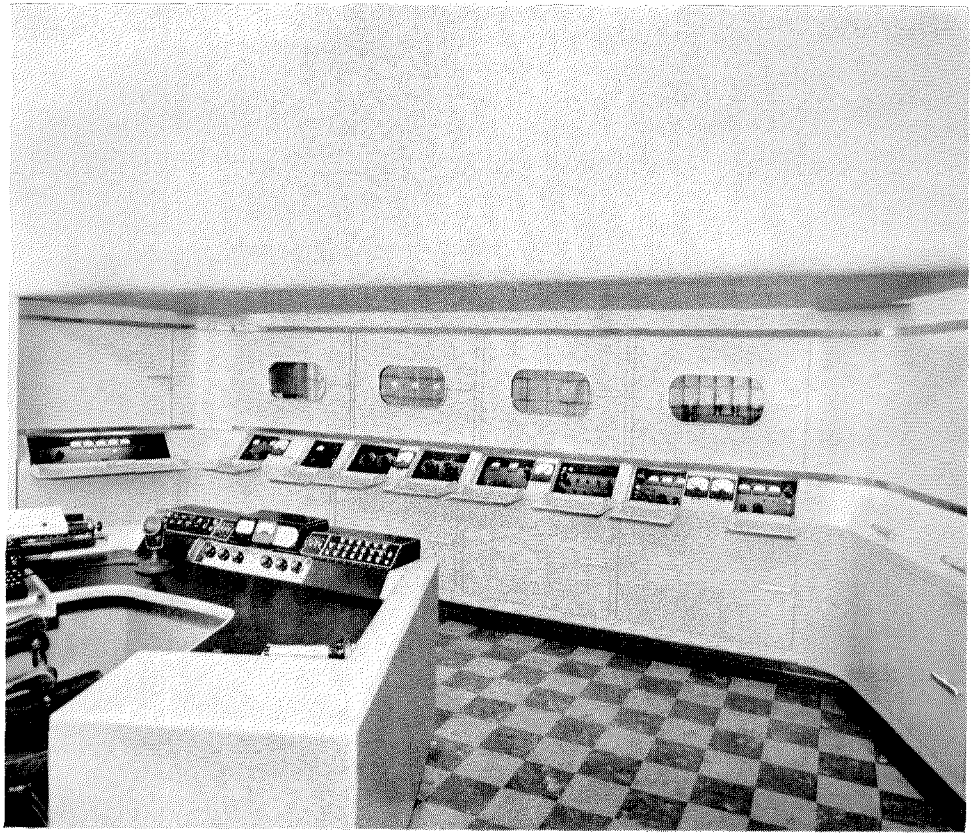

CONTROL ROOM OF RADIO STATION WDOD, CHATTANOOGA, TENNESSEE, SHOWING FRONT PANEL ARRANGEMENT AND CONTROL DESK OF NEW 5 KILOWATT BROADCAST TRANSMITTER DESIGNED AND BUILT BY THE FEDERAL TELEGRAPH COMPANY.

The Evolution of Wire Transmission*

By GEORGE H. GRAY
International Standard Electric Corporation, New York, N. Y.

THE importance of recent developments in telephone wire transmission systems may best be appreciated from a brief historical review of the progress achieved in such systems since the early days of the telephone. Such a review is given herein, followed by a brief discussion of the important economic implications of the newer broad band systems—12-channel carrier and coaxial cable.

The review may be divided conveniently into three periods, plus a fourth now well started. Important additions to available types of plant permitted advances during each period in at least three of the following respects:

1. Conversation distance;
2. Transmission channels obtainable from a pair of conductors;
3. Frequency band transmitted and, hence, improved quality and naturalness of conversation;
4. Reliability of service.

1. 1876–1900

The first period, roughly twenty-five years, ended about 1900. Although conversation then was still limited to one per pair of wires (neglecting the ground return telephone circuit and the simultaneous use of wires for telephone and telegraph purposes), reliability of service and transmitted quality had been improved and the transmitting distance increased considerably. This was accomplished largely by the use of copper instead of iron wire, better insulators, improved line construction and carefully designed transposition schemes. These changes involved no additions to the inside plant and no increased complications in the outside plant other than the necessity for properly maintaining the transpositions.

The restriction in the transmitting distance at the close of this period was largely economic due to the fact that, as the distance increased, the quantity of copper required per kilometer for a given line attenuation rose steeply. This is indicated in Fig. 1, Curve *A*, which shows the weight of copper needed, per circuit-kilometer, for circuits up to 200 km (125 miles) in length with a total overall attenuation of 10 db.

Using 4.19 mm (0.165 inch) copper wire, conversation under favorable conditions was possible by the end of this period over distances of nearly 1,600 km (1,000 miles).

2. 1900–1915

The second period, extending from 1900 to about 1915, was marked by the introduction of phantom circuits (invented earlier but not used commercially until about 1903), loading coils and quadded toll cable. These changes resulted in a 50% increase in the circuit capacity of a pair of wires and in slightly more than doubling the transmitting distance of open wire circuits. The use of underground toll cable of course improved the reliability of service. Unfortunately, the use of loading limited the frequency band which could be transmitted. In some cases this band was confined to frequencies below approximately 1,800 cycles, and this affected the quality of the transmission.

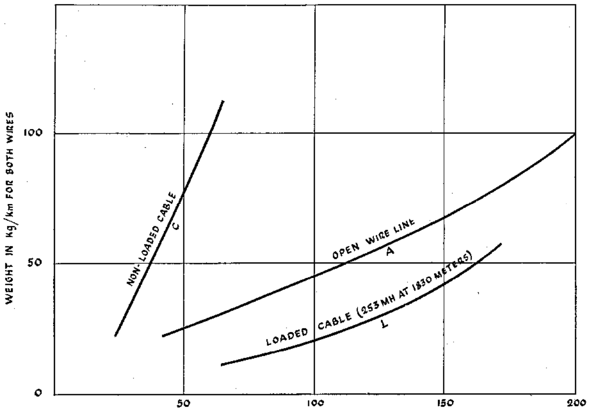

Fig. 1—Copper Requirements per km for Circuit Having 10 db Loss.

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* The material for this article was prepared originally by Mr. S. Van Mierlo while associated with Laboratoires Le Matériel Téléphonique, Paris. It was submitted via London prior to September, 1939, and has been rearranged and amplified by the present author.

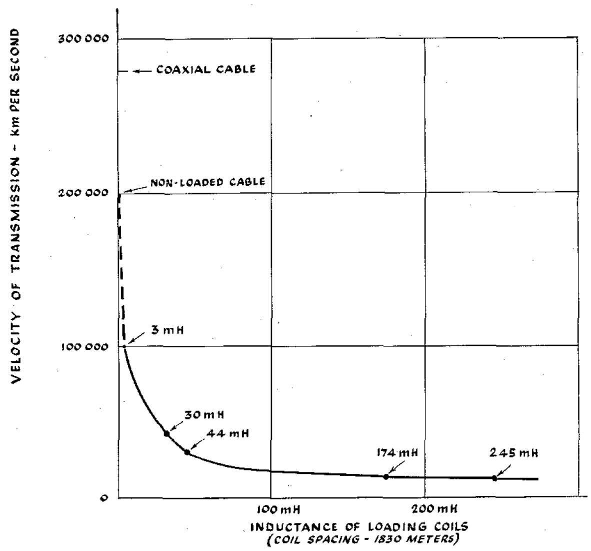

Fig. 2—Speed of Propagation.

The introduction of loading coils also reduced the speed of transmission, thus bringing about potential difficulties from transient and echo effects. However, this was not particularly objectionable at the time since the circuits involved were comparatively short. The change in transmission speed with change in weight of loading is shown by Fig. 2, in which the coils are assumed to be spaced at 1,830 meters (6,000 feet).

Fig. 1, Curves *C* and *L*, respectively, gives the weight of copper needed per circuit kilometer for an overall voice frequency attenuation of 10 db for non-loaded cable and for cable loaded with 253 mh coils spaced at 1,830 meters. The copper requirements of non-loaded cable obviously far exceed those of open wire so that such cables, by themselves, are practicable only for short distances. Loading, as is well known, greatly reduces the amount of copper required; in fact, for the particular conditions assumed, the loaded cable circuit requires only a little more than half the copper necessary for the non-loaded open wire circuit.

With a view to reducing the amount of copper required for a given distance (or increasing the distance for the same amount of copper), a scheme was tried using microphones to control higher power than was practicable with the ordinary carbon microphone, i.e., to increase the total permissible attenuation in the transmission system. Various water-jet microphones were constructed, but high first cost and maintenance expense made such a solution unsuitable for use at subscribers' stations.

The inside plant was made slightly more complex by the phantom repeating coils, and the loading made necessary certain precautions in the maintenance of the outside plant. In general, however, it can be said that this period added little to the plant complexity.

3. 1915–1937

The third period, beginning about 1915 and lasting until perhaps 1937, included the introduction of some radically different and very important types of plant such as the:

a. Vacuum tube repeater
b. 4-wire circuit
c. 1 and 3-channel carrier systems
d. Radio links

During the last few years of the second period (1900–1915) interesting service results had been obtained with "mechanical" repeaters, consisting essentially of combination microphones and telephone receivers. Certain inherent disadvantages, however, were involved and this combination was abandoned soon after the advent of the vacuum tube repeater.

The vacuum tube repeater at once more than doubled the transmitting distance of open wire circuits and, by making possible the removal of open wire loading, permitted the transmission of an increased band width. In cable circuits, repeaters permitted a reduction in the weight of loading and hence an increase in the band width and in the speed of propagation. The 4-wire circuit greatly increased the transmitting range for cable. The 3-channel carrier made it possible

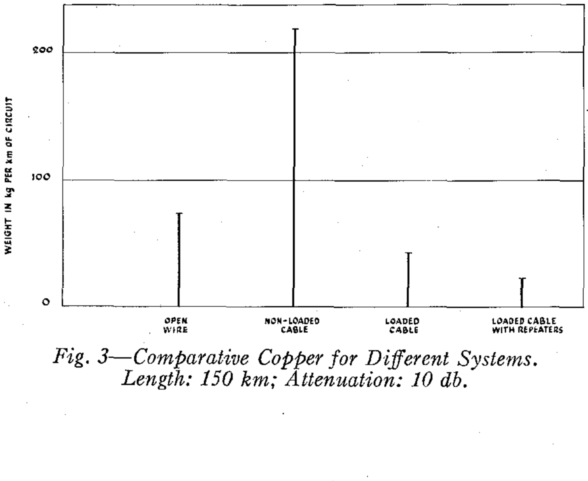

Fig. 3—Comparative Copper for Different Systems. Length: 150 km; Attenuation: 10 db.

to obtain nine circuits from an open wire phantom group where only three could be obtained before—a threefold increase in capacity. And by combining transoceanic radio links with land circuits, the transmitting range was increased to such an extent that a conversation around the world was held in 1935 over a route of approximately 36,000 km (23,000 miles): New York–London–Amsterdam–Java–San Francisco–New York. Obviously, these advances were not obtained without an increase in the complexity of the plant. It became necessary to maintain repeaters, carrier terminal equipment, radio terminal equipment, special transposition schemes, etc.; but, on the whole, no very serious difficulties were encountered. This was due, in no small measure, to special plant personnel training courses conducted at appropriate intervals.

For a circuit length of 150 kilometers (about 90 miles) and an overall voice frequency attenuation of 10 db, the copper required per kilometer is shown in Fig. 3 for open wire circuits, non-loaded cable, loaded cable and loaded cable with repeaters. The relative copper reduction in the case of the repeater systems obviously would be far greater if an overall attenuation less than 10 db were assumed.

Particularly in carrier and in 4-wire systems the total attenuation of a long distance circuit can be maintained at a very low value (often below 3 db) in the transit condition by the use of repeaters. This low attenuation is most important from the viewpoint of economy in regional networks, inasmuch as the total attenuation equivalent between two subscribers (say 25 to 35 db) can then be almost entirely absorbed by these networks.

Summarizing, vacuum tube repeaters and 3-channel open wire carrier systems made possible a practically unlimited increase in transmission range and an improvement in transmission quality. Their introduction, moreover, influenced toll rate decreases appreciably. Nevertheless, outside plant expenditures remained a fairly large factor in the cost of furnishing toll telephone service. Consequently considerable attention naturally was devoted to possibilities of further reductions in outside plant costs.

With near-zero-equivalent circuits already available on conductors approaching the minimum size imposed by mechanical limitations, the most promising solution seemed to be a further increase in the number of circuits obtainable per pair of wires. This, of course, involved an increase in the frequency band transmitted and, unfortunately, greater transmission losses and crosstalk due to the application of higher frequencies.

The negative feedback repeater, special transposition schemes for open wire lines, the separation of the "go" and "return" conductors in cables, special entrance cables, very careful balancing of all circuits, improved filters, dry metallic modulators and demodulators, and many other developments made possible the application of higher frequencies to existing types of plant and paved the way for the next period in the history of wire transmission systems.

4. 1937–

This fourth period, now well initiated, commenced about 1937 and may be designated as the "broad band" period of wire transmission. The more important developments include:

a. 12-Channel open wire carrier
b. 12-Channel cable carrier
c. Coaxial cable

Although definite predictions would be somewhat premature, present indications are that progress during this period will exceed even that of the previous period.

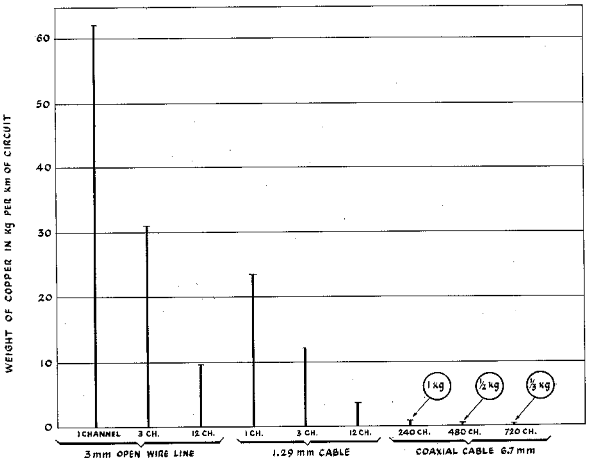

Fig. 4—Comparative Copper for Different Carrier Systems.

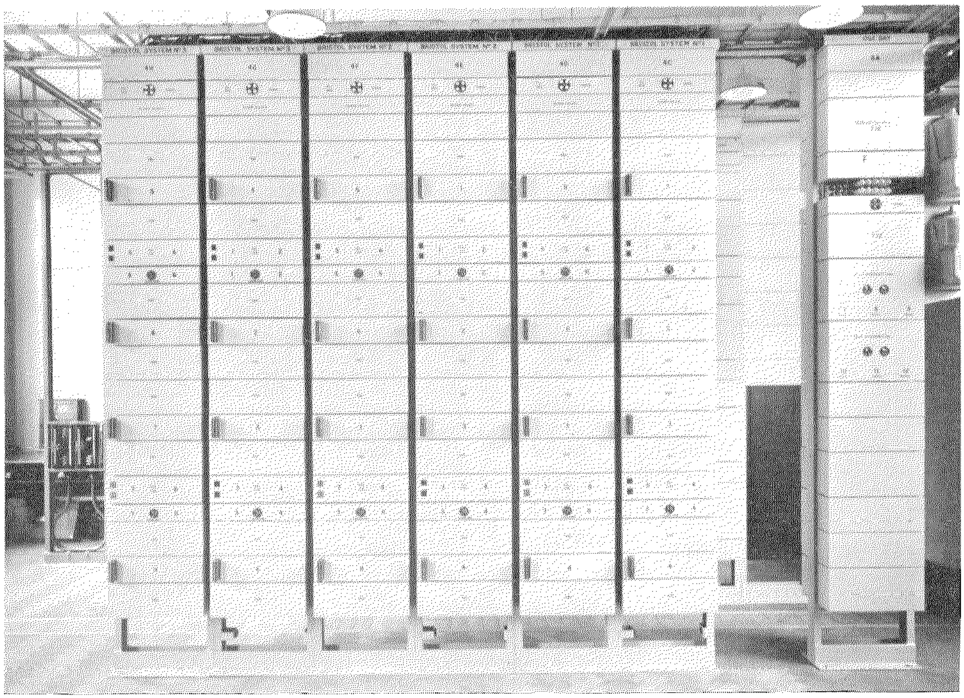

Fig. 5—General View of Terminal Equipment. One of first 12-channel carrier-on-cable installations, showing oscillator, channel and amplifier bays.

An indication of the results obtainable with 12-channel carrier current systems can be visualized from Fig. 4, which shows the copper weight, for both open wire and cable, per unit of channel circuit length (voice plus carrier) in various transmission systems. The copper reduction effected in 12-channel systems is striking.

This reduction must not be taken as representing the relative reduction in *plant costs* since its accomplishment requires a considerable expenditure for equipment (carrier terminal apparatus, repeaters, balancing equipment, etc.); and also, in the case of the open wire carrier, necessitates special transpositions, the installation of new types of entrance cables and other important items.

Loading requirements for cable, it is pertinent to note, have been decreased from 44 mh for voice frequency to 22 mh in the single channel system, to 3 mh in the 3-channel system, and to zero in the 12-channel system. Simultaneously, propagation velocity has been increased radically (Fig. 2).

Loading performed an important service in improving transmission. However, the necessity for transmitting a wider frequency range at higher speeds has now brought about its abandonment for the highest grade of circuits in both open wire and cable.

In the case of 12-channel systems, it might be thought that elimination of loading and the necessity for frequencies up to 60 kc per second would prevent their commercial application. Actually, however, attenuation of 1.29 mm conductors in 12-channel cable systems is about 1.6 db per km (2.6 db per mile) at 60 kc per second, a value which is quite admissible in view of the fact that it is practical in this case to work the channels at an attenuation of approximately 60 db per section with repeaters spaced at intervals of about 35 km (22 miles). Development of these repeaters has progressed to a point where about two out of every three repeater stations can generally be operated on an unattended basis.

The reasons for this high permissible attenuation are very low outside interference at high frequencies and the use of separate cables for the two directions or, alternatively, a single copper-screened cable to reduce interference between the go-and-return channels. As is well known, the limit of amplification, or attenuation, is determined by the signal-noise ratio: low outside interference and low crosstalk result in decreased noise. Speech or transmission signals, therefore, may be correspondingly reduced, i.e., very high level differences between the beginning and end of a cable section are permissible.

An inherent advantage of 12-channel systems, highly significant from an economic viewpoint, results from the importance of installing cables sufficiently large to provide adequately for future growth. Since cable cost represents the greater part of the total outlay for a non-carrier system, the initial investment in cables is ordinarily great and full realization of returns must be deferred until they are worked at full capacity. In 12-channel systems the initial investment, on the contrary, is relatively low, and terminal equipment can be added when required. Moreover, in 12-channel cable systems, the initial investment is not only lower, but a better balance between outlay and revenue can be attained over the entire period of use.

It should be emphasized that no attempt was made to reduce the width of the frequency band when the number of channels was increased. Long experience and extensive research, in fact, have demonstrated the importance of transmitting a relatively wide frequency band (250–3400 p:s, for example). The practical ultimate criterion of transmission quality obviously involves faithfulness of reproduction, as well as the signal level and freedom from noise. The subscriber's choice is the circuit which "speaks best." A wide band width, moreover, makes it possible to reduce the transmission level, especially if the noise is low. Then too, if the transmission loss in a long distance link is reduced to zero, the total allowable losses can be concentrated in the local networks with considerable decrease in their cost. Further, this loss may be increased by several db for the same overall effective transmission, provided the width of the transmitted frequency band is adequately increased. To derive the full benefit from the widening of the band, the subscribers'

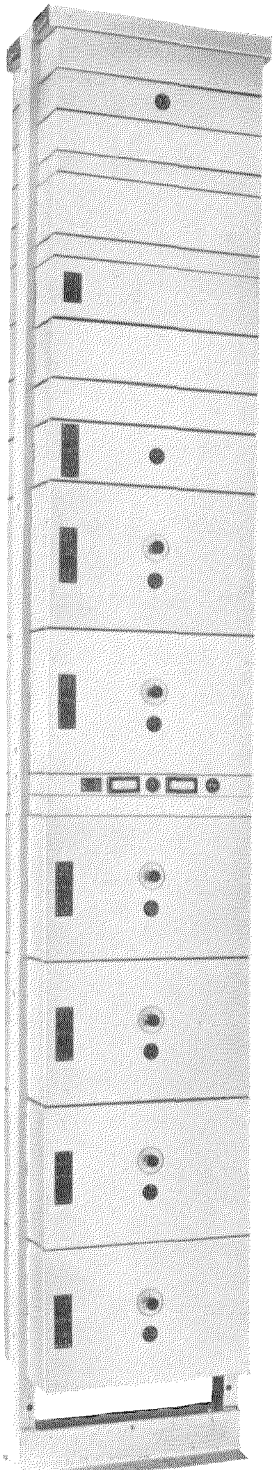

Fig. 6—Later Type of Channel Bay—12-Channel Carrier System. The bay contains complete equipment for one group of 12 channels with the exception of the terminating sets.

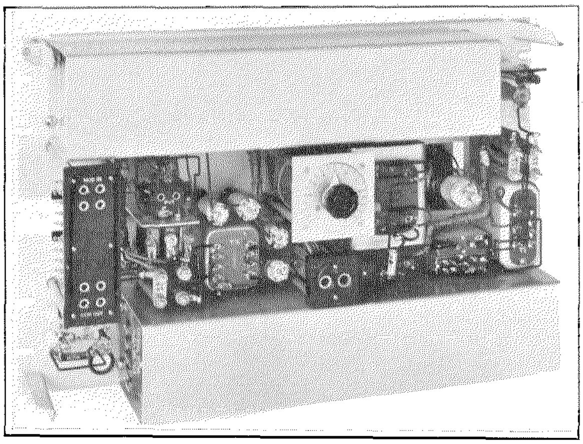

Fig. 7—Modulator-Demodulator Panel—12-Channel Carrier System.

apparatus—transmitter and receiver—obviously must be capable of producing and reproducing this band. Such subscribers' apparatus has been developed and introduced into commercial use.

The propagation velocity over 12-channel cable systems is about 200,000 km/s (125,000 miles per second), i.e., instantaneous for all practical purposes. Even on the longest lines, therefore, speech quality is not appreciably diminished by echoes or other phenomena due to low propagation speed. Consequently, lines may be interconnected at will.

In local networks, the economic advantage to be derived from linking up distribution centers by means of cables is clear. Interconnection of all subscribers, or even all groups, evidently would involve a prohibitive outlay. Similarly, in certain cases, the principle of distribution centers interconnected by cable might be extended to international networks, supplemented by carrier current cables radiating towards the principal regional towns.

It is thus apparent that the 12-channel system, along with inherent economy and improved transmission quality, facilitates the introduction of more economical networks.

Because of the advantages of the 12-channel carrier cable system the British General Post Office immediately adopted it for its principal toll networks; the first of such systems was installed in England even before the close of 1936. Shortly thereafter systems were installed in other countries, including the United States, France, Rumania, Sweden, Finland, Holland and Belgium.

Fig. 5 gives a general view of the terminal equipment of one of the early installations, while Fig. 6 illustrates a later type of channel bay. Fig. 7 shows the modulator-demodulator panel, comprising two crystal filters. Fig. 8 is a view of a crystal filter.

Coaxial Cables

For use where very large numbers of telephone circuits were needed and for television (which requires cables capable of transmitting a frequency band of at least 2 mc/s), consideration was given to the application of coaxial cables. Their speech channels, as is now well known, are counted in hundreds rather than in dozens. Even for cables of small diameter, frequencies of the order of several megacycles can be handled; and, since telephone channels are spaced at 4 kc/s, several hundred voice channels can readily be made available. In such cases,

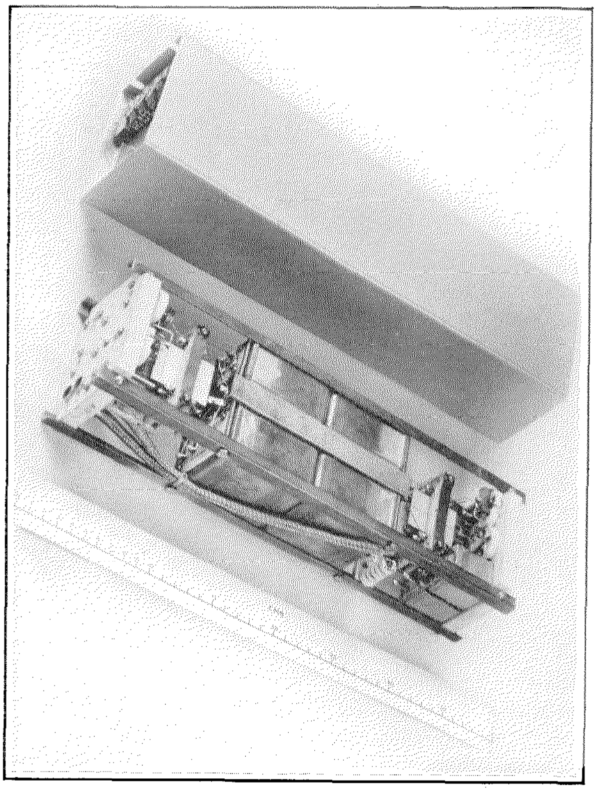

Fig. 8—Complete Crystal Channel Filter Shown in Case and with Cover Removed—12-Channel Carrier System.

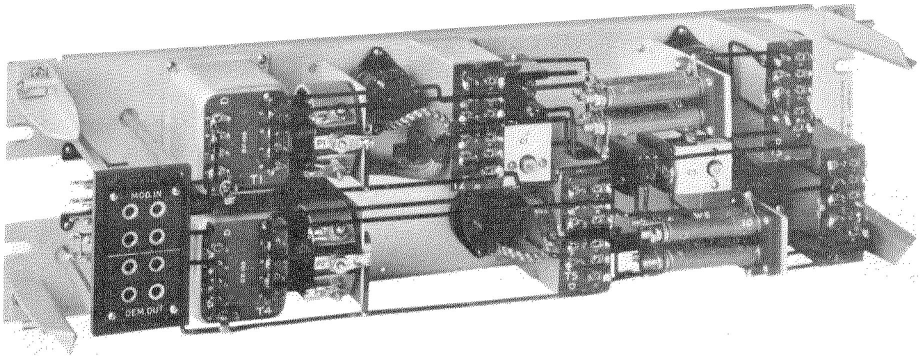

Fig. 9—Group Modulator-Demodulator.

the copper equivalent per speech circuit is extremely low (Fig. 4).

In practice, hundreds of transmission channels between points separated by considerable distances are rather infrequently required. However, if a demand for television channels should arise, this no doubt would result in the installation of coaxial cables and probably additional coaxial units could be added economically for telephone channels. For other installations 12-channel systems appear at present to be more attractive except for long, very heavy traffic routes.

In Europe, coaxial cables have been laid in England, France and Germany. In the U. S. A., a cable containing two 6.7 mm coaxial lines has been installed between New York and Philadelphia (150 km; 90 miles), and another four-line coaxial cable recently was placed in commercial telephone service between Stevens Point, Wisconsin, and Minneapolis, Minnesota (over 300 km; 200 miles).

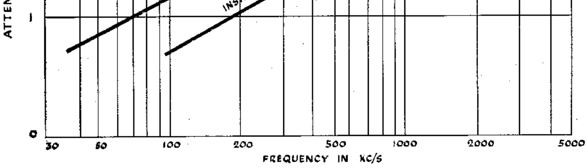

Fig. 10—Attenuation of Coaxial Cables.

The terminal equipment of a coaxial cable system is, in part, identical with that of the 12-channel system. Additional equipment is, however, required to transfer the 12-channel groups into a higher region of the frequency spectrum. Fig. 9 shows a modulator-demodulator capable of effecting this change.

Attenuation values for coaxial cables with internal diameters for the external conductor of 6.7 mm and 9.5 mm are given in Fig. 10. The external conductor, at least above 50 kc/s, serves as a very effective screen against external interference. Hence, very low signal levels, permitting attenuation of 45–60 db per section between repeaters, are acceptable. In a cable of 6.7 mm internal diameter, intervals between repeaters of about 8 km are thus admissible with a frequency band extending up to 3 mc/s. For purposes of comparison, typical repeater spacings and attenuations for various transmission systems are given in Fig. 11, a 240 km (150 mile) line being assumed in each case.

In coaxial cable systems, the total attenuation for a long line is obviously very high. For example, a 1,000 km (625 mile) coaxial cable (6.7 mm), capable of transmitting a frequency band suitable for 300 telephone channels, would have an attenuation of about 4,500 db. Since reception levels must be maintained within restricted limits (about plus or minus 1 db), repeaters must have a high degree of stability. The net result is a permissible tolerance of about 0.01 db per repeater. Furthermore, from the standpoint of distortion and noise, these repeaters must meet stringent requirements. A very satisfactory solution is provided by the application of feedback repeaters.

The attenuation of the cable itself, either of the coaxial or 12 channel type, varies with temperature so that very long circuits, especially if in aerial cables, necessitate the introduction of compensation devices. For underground cables, manual compensation may be used; for aerial cables, automatic compensation is required due to more rapid temperature fluctuations. Recently a simplified regulating method (using devices known as "thermistors," whose resistance varies with temperature in the required manner) has been developed and is expected largely to replace the former rather complicated mechanism.

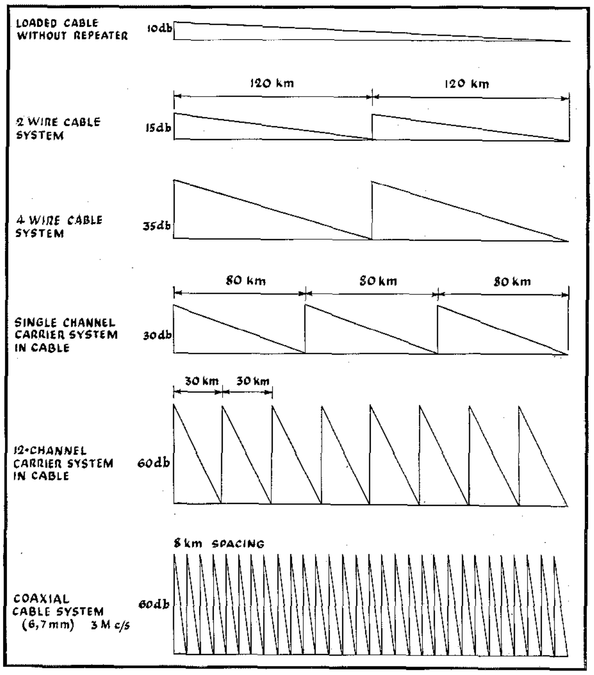
LOADED CABLE WITHOUT REPEATER
10db
120 km
120 km
2 WIRE CABLE SYSTEM
15db
4 WIRE CABLE SYSTEM
35db
80 km
80 km
80 km
SINGLE CHANNEL CARRIER SYSTEM IN CABLE
30db
30 km
30 km
12-CHANNEL CARRIER SYSTEM IN CABLE
60db
8 km SPACING
COAXIAL CABLE SYSTEM (6,7mm) 3 M c/s
60db

Fig. 11—Typical Repeater Spacings and Attenuations for Various Systems.

Table I and Fig. 12 indicate the results attained in reducing repeater weights and floor space requirements. These show comparative figures, per station, for a group of 240 channels, assuming the use of a 12-channel basic unit for the cable carrier. The results would obviously differ slightly for some of the conditions if a different number of channels had been assumed for the basic unit.

TABLE I

Type of System	Requirements per Repeater Station for 240 Channels		
	No. of Bays	Weight in Kgs	
		Per Channel	Total
Cable			
4-wire Systems—1st type (1926)	64	75	18,000
New type (1931)	28	35	8,400
2-wire Systems—1st type (1926)	64	83	20,000
New type (1931)	44	50	12,000
Carrier on Cable			
1+1 Channel, recent type	10	13	3,000
12-Channel	7	10	2,500
Coaxial	1	1	240

In the case of equipment for coaxial cable, the dimensions and weight (total) of repeaters would not increase even if the number of channels considerably exceeded 240. The equipment, moreover, includes a 100% repeater reserve.

Terminal equipment has been simplified and the weight per channel reduced. In a 3-channel open wire system, three bays were required ten years ago; today, one bay suffices for the principal equipment.

Relative sizes of filters, modulator elements, and complete modulators and demodulators for old and new systems are shown in Fig. 13. In general, the reduction in space required is of the order of 4 to 1.

Conclusion

Although the new transmission systems available in this fourth period of development make use of apparatus which at first glance may appear complicated, there seems to be no reason,

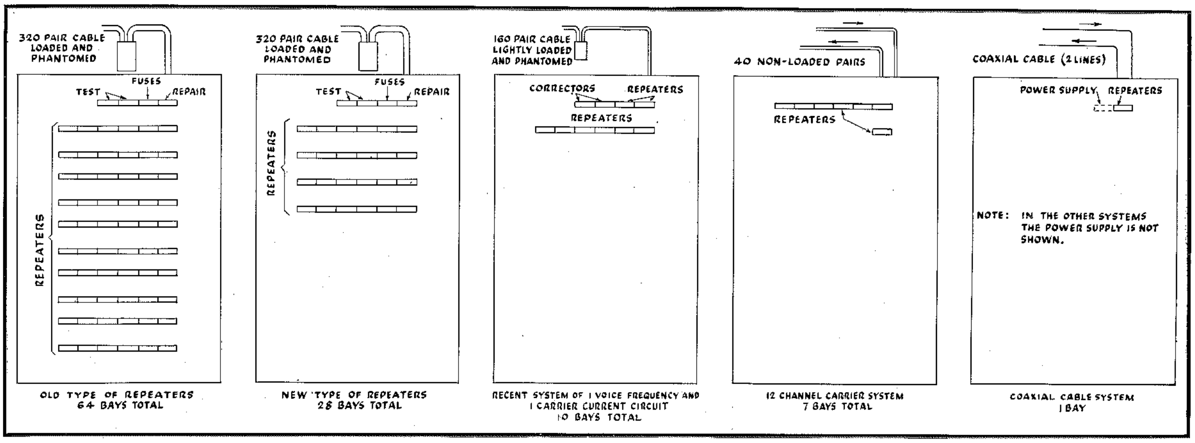
320 PAIR CABLE LOADED AND PHANTOMED
TEST
FUSES
REPAIR
REPEATERS
OLD TYPE OF REPEATERS
64 BAYS TOTAL
320 PAIR CABLE LOADED AND PHANTOMED
TEST
FUSES
REPAIR
REPEATERS
NEW TYPE OF REPEATERS
28 BAYS TOTAL
160 PAIR CABLE LIGHTLY LOADED AND PHANTOMED
CORRECTORS
REPEATERS
REPEATERS
RECENT SYSTEM OF 1 VOICE FREQUENCY AND 1 CARRIER CURRENT CIRCUIT
10 BAYS TOTAL
40 NON-LOADED PAIRS
REPEATERS
12 CHANNEL CARRIER SYSTEM
7 BAYS TOTAL
COAXIAL CABLE (2 LINES)
POWER SUPPLY
REPEATERS
NOTE: IN THE OTHER SYSTEMS THE POWER SUPPLY IS NOT SHOWN.
COAXIAL CABLE SYSTEM
1 BAY

Fig. 12—Comparative Space Requirements for Repeaters.

based on extensive experience to date, to expect any more serious reaction from their application than was encountered with innovations during the other three periods.

The coaxial repeaters, especially, do not require auxiliary equipment. Furthermore, they may be installed in small, simple structures, or be enclosed in metallic housings placed on poles or in underground chambers. The relatively large number of repeaters necessary is no cause for concern. Experience has demonstrated conclusively that the manufacture of repeaters involving minimum risk of breakdown is a practical proposition; and, in addition, arrangements are such that either an individual repeater or a complete cable and repeater section may be replaced automatically by a reserve repeater or a complete reserve section.

The new systems represent a most important advance in long distance communication engineering. Moreover, their development has progressed to the point where they can be considered commercially stabilized to the extent that no radical modification in the structure of cables, repeaters or terminal equipment is to be anticipated. It therefore seems evident that such broad band systems can confidently be taken as the basis for studies of new networks, affording possibilities of rate reductions and of effecting an extraordinary development in high quality long distance telephone communications. Further, their advent makes practical, in many instances, provision for the introduction of television networks on an international scale.

Advances during the first two periods were effected largely with material and apparatus placed in the field, i.e., "outside plant"; those of the third period depended largely on central office equipment. While an important element in progress during the fourth period doubtless must be credited to central office equipment (such as the terminal apparatus for the coaxial and 12-channel systems), it appears that a new essential factor will be the adaptation of apparatus heretofore regarded as central office equipment to utilization in the field. This new apparatus, as previously indicated, has been embodied in unattended repeater stations.

The list of papers appended describes in detail some of the above mentioned developments.

Bibliography

1. "Commercial Loading of Telephone Circuits in the Bell System," by B. Gherardi, *A.I.E.E. Trans.*, 1911, p. 1743.
2. "Telephone Repeaters," by B. Gherardi, *El. Com.*, Vol. 1, Nos. 1 & 2, 1922.
3. "Modern Loading Equipment," by J. B. Kaye, *El. Com.*, Vol. 10, Nos. 3 & 4, 1932.
4. "The London-Glasgow Trunk Telephone Cable and Its Repeater Stations," by A. B. Hart, *El. Com.*, Vol. 5, No. 2, 1926.
5. "Carrier Current Telephony and Telegraphy," by E. H. Colpitts and O. B. Blackwell, *A.I.E.E. Trans.*, 1921, p. 205.
6. "Carrier Systems on Long Distance Telephone Lines," by H. A. Affel, C. S. Demarest, and C. W. Green, *A.I.E.E. Trans.*, 1928, p. 1360; *B.S.T.J.*, July, 1928.
7. "Two-Way Telephone Conversation Is Held Entirely Around the World," *Bell Tel. Mag.*, July, 1935.
8. "Carrier Telephone System for Short Toll Circuits,"

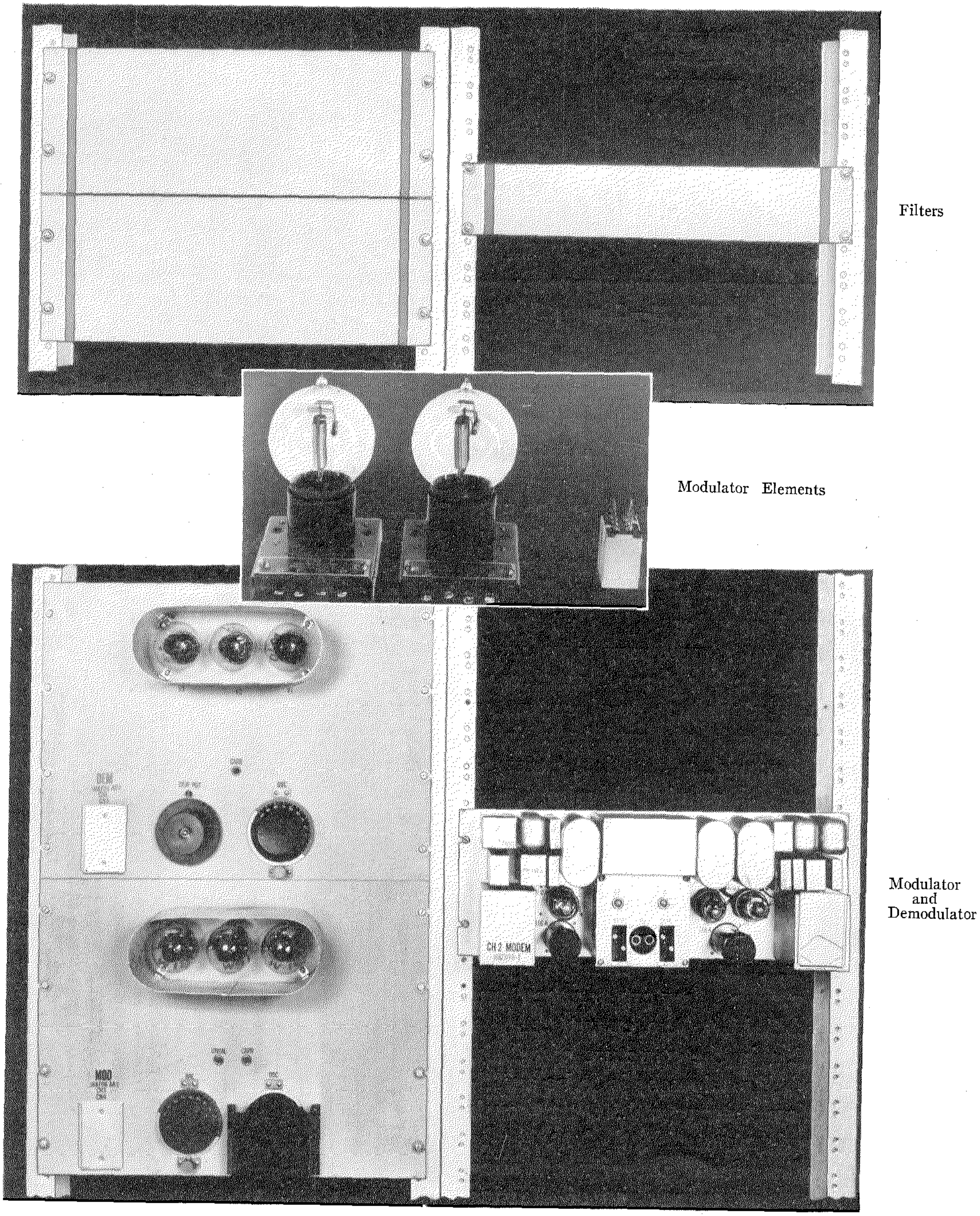
Filters
Modulator Elements
DEM
MOD
CH 2 MODEM
Modulator and Demodulator

Fig. 13—Comparative Size of Elements of Old and of New Systems.

by H. S. Black, M. L. Almquist, and L. M. Ilgenfritz, *A.I.E.E. Trans.*, 1929, p. 117.

9. "Stabilized Feedback Amplifiers," by H. S. Black, *B.S.T.J.*, Jan., 1934.
10. "A New Single Channel Telephone System," by H. J. Fisher, M. L. Almquist, and R. H. Mills, *A.I.E.E. Trans.*, 1938, p. 25; *B.S.T.J.*, Jan., 1938.
11. "The Carrier Telephone and Telegraph Equipment of the New Bass Strait Submarine Cable System," by F. Ralph and R. L. Hughes, *El. Com.*, Vol. 15, No. 4, 1937.
12. "Fundamental Transmission Planning of Telephone Networks," by B. H. McCurdy, *El. Com.*, Part I: Vol. 18, No. 1, 1939; Part II: Vol. 19, No. 1, 1940.
13. "Carrier in Cable," by A. B. Clark and B. W. Kendall, *A.I.E.E. Trans.*, 1933, p. 1050; *B.S.T.J.*, July, 1933.
14. "Modern Systems of Multi-Channel Telephony on Cables," by A. S. Angwin and R. A. Mack, *Jnl. of I.E.E.*, April, 1937.
15. "Bristol-Plymouth 12-Channel Carrier System," *El. Com.*, Vol. 16, No. 2, 1937.
16. "A Carrier Telephone System for Toll Cables," by C. W. Green and E. I. Green, *A.I.E.E. Trans.*, 1938, p. 227; *B.S.T.J.*, Jan., 1938.
17. "Cable Carrier Telephone Terminals," by R. W. Chesnut, L. M. Ilgenfritz, and A. Kenner, *A.I.E.E. Trans.*, 1938, p. 237; *B.S.T.J.*, Jan., 1938.
18. "Crosstalk and Noise Features of Cable Carrier Telephone System," by M. A. Weaver, R. S. Tucker, and P. S. Darnell, *A.I.E.E. Trans.*, 1938, p. 250; *B.S.T.J.*, Jan., 1938.
19. "Crystal Channel Filters for the Cable Carrier System," by C. E. Lane, *A.I.E.E. Trans.*, 1938, p. 245; *B.S.T.J.*, Jan., 1938.
20. "Wide Band Transmission Over Coaxial Lines," by L. Espenschied and M. E. Strieby, *El. Com.*, Vol. 13, No, 2, 1934; *A.I.E.E. Trans.*, 1934, p. 1371; *B.S.T.J.*. Oct., 1934.
21. "A Million-Cycle Telephone System," by M. E. Strieby, *El. Com.*, Vol. 16, No. 1, 1937; *B.S.T.J.*, Jan., 1937.
22. "Wide Band Transmission Over Balanced Circuits," by A. B. Clark, *El. Com.*, Vol. 13, No. 4, 1935; *A.I.E.E. Trans.*, 1935, p. 27; *B.S.T.J.*, Jan., 1935.
23. "A Twelve-Channel Carrier Telephone System for Open-Wire Lines," by B. W. Kendall and H. A. Affel, *A.I.E.E. Trans.*, 1939, p. 351; *B.S.T.J.*, Jan., 1939.
24. "J-12 Open-Wire Carrier System," by C. J. Griffiths, *Tel. Com. of Australia*, Oct., 1938.
25. "Some Applications of the Type J Carrier System,", by L. C. Starbird and J. D. Mathis, *A.I.E.E. Trans.* 1939, p. 666; *B.S.T.J.*, April, 1939.
26. "Line Problems in the Development of the Twelve-Channel Open-Wire Carrier System," by L. M. Ilgenfritz, R. N. Hunter and A. L. Whitman, *A.I.E.E. Trans.*, 1939, p. 658; *B.S.T.J.*, April, 1939.
27. "Copper Oxide Modulators in Carrier Telephone Systems," by R. S. Caruthers, *A.I.E.E. Trans.*, 1939, p. 253; *B.S.T.J.*, April, 1939.
28. "The Sydney-Melbourne Type J Carrier Telephone System," by J. T. O'Leary, J. B. Scott and A. M. Thornton, *El. Com.*, Vol. 19, No. 1, 1940.
29. "12-Channel Carrier Equipment in the Göteborg-Malmö Cable," by S. R. Nordström, *El. Com.*, Vol. 20, No. 2, 1941.
30. "Irregularities in Telephone and Television Coaxial Cables," by L. Brillouin, *El. Com.*, Vol. 17, No. 2, 1938.

Voice-Frequency Signalling and Dialling in Long-Distance Telephony[*]

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During the 21 years between the two great European wars telephone systems of the majority of the cities and large towns of the world have been converted from manual to automatic operation. During the same period notable improvements have also been made to the long-distance telephone service.

The introduction of the use of voice-frequency currents for signalling and dialling represents a stage in a long process of development, and the main portion of this paper describes the problems encountered in the design of a system and the various methods which may be employed for avoiding interference between signals and other currents in the voice-frequency range. Reference is also made to the recommendations of the C.C.I.F. regarding the means of avoiding interference between different signalling systems on international connections.

The interruption in development caused by the present war provides an opportunity for a review of the progress made and for a consideration of future lines of development necessary to keep pace with changes in automatic switching and speech transmission. Therefore, while the paper starts by setting forth the reasons for modern methods of signalling and dialling over long-distance circuits and for preferring the use of voice-frequency currents for these purposes, it concludes by considering the possible trend of future development.

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- (7) Bibliography.

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[*] Paper presented before The Institution of Electrical Engineers on the 18th December, 1941.

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(1) *The Justification for the Use of Automatic Signalling and Dialling Over Long-Distance Circuits*

MUCH has been achieved in the development of telecommunication systems, and many advances in science have already been transmuted into better service to the subscriber. During the present century considerable improvements have been made in the quality of the received speech, and the distance over which telephone calls are made has been very greatly increased. What is now required is a reduction in the time taken to set up, release and obtain supervision of long-distance connections. Long-distance signalling and dialling by means of voice-frequency currents meet these requirements. By these means the facilities existing in many cities for local calls are extended to the long-distance telephone network. In the present review these facilities will be compared with contemporary practice as operated on modern manual toll switchboards.

Prior to the advent of signalling by more recent methods utilizing voice-frequency currents at 600 and 750 c./s. it had been the practice in Europe to use currents at 500 c./s. for signalling to switchboard operators.[2] This frequency can be transmitted over the normal long-distance circuit with less loss than 16 c./s., which is a customary frequency for ringing a subscriber's bell. The presence of 500 c./s. in speech caused false signals and unnecessary intervention by the operator. In consequence it was found advisable to introduce a time delay and to modulate or interrupt the ringing current by a lower frequency such as 16 or 20 c./s. because the occurrence in speech of the combination of high and low frequencies is of short duration.

Signalling on long-distance circuits by means of 500 c./s. with low-frequency modulation provides a service similar to that of the magneto switchboard which commenced its long journey into obsolescence and obscurity more than 30 years ago. The following processes are involved: The operator at the outgoing end rings down the line —this expression seems more appropriate than "the operator at the outgoing end rings the operator at the incoming end," because frequently the latter is already occupied in setting up a call and, therefore, cannot give immediate attention. The "outgoing" operator then listens on the line and, if necessary, re-rings. The requirements are passed, the "incoming" operator connects the wanted party and the "outgoing" operator reconnects the calling subscriber if previously released from the circuit. The "outgoing" operator monitors to make sure that the conversation starts satisfactorily as regards speech level and correctness of connection and then retires. On receipt of a signal from the calling subscriber, the "outgoing" operator re-enters the circuit, challenges that the conversation is complete, releases the local side of the connection and then rings off over the long-distance line. This signal is duly received by the "incoming" operator, who enters the circuit, challenges, and then releases the remainder of the connection. It will be appreciated that, if three or more operators are necessary to build up a call through intermediate switching points, the complication is increased, due in part to the possibility that the connecting circuits are not available when required and the probability that the three or more operators are not available simultaneously at the moment when it is desired to recall one or other of the subscribers or to take down the connection.

This series of operations conforms precisely to that carried out on short-distance circuits between magneto switchboards and is commonly known as "magneto working." Supersession of magneto working by common battery (C.B.) working on local manual switchboards introduced automatic signalling over short-distance circuits. With automatic signalling supervisory lamps are lit, dimmed or flashed to indicate the condition of the circuit, and events take place in sequence. After the "outgoing" operator has sent a calling signal, a supervisory lamp indicates when the "incoming" operator is connected to the circuit and the call requirements are passed. The "outgoing" operator receives lamp supervision when either party clears and is, therefore, called in automatically if the connection is terminated prematurely. In conclusion, the whole connection is released by the "outgoing" operator without awaiting the assistance of the "incoming" operator, provided that the latter has set up the incoming end of the connection by automatic connecting circuits rather than by cords and plugs. The advantage obtained by automatic signalling lies in the speedier operating because of precise knowledge of the action at the distant end of the line. In addition the "outgoing" operator is saved the distress and delay liable to occur when plugging into a long-distance circuit which has not yet been released from the previous connection at the incoming end. The increase in the speed of setting up and taking down each connection improves the traffic-handling capacity of the line plant. Provision of special recall and transfer facilities, which become possible when a range of different signals is available, simplifies the operating procedure and avoids wastage of time and effort.

The acceptance of the superiority of C.B. over magneto working on local manual switchboards is world-wide, and it is evident from the above considerations that the same reasoning may be applied to long-distance circuits.[3] This generalization applies to exchange areas into which it is impossible to dial. It applies similarly to cases in which dialling over the long-distance line can only be carried out in one direction because one termination is still operating on a manual basis. If the provision of suitable automatic connecting circuits without cords and plugs is inconvenient at the incoming end of the long-distance line, the release of the connection is likely to be under the joint control of both "outgoing" and "incoming" operators with consequential delay. In these circumstances the potential operating advantages cannot be fully realized.

When the long-distance line can be terminated on automatic switches rather than a manual switchboard, the ability to dial the number required eliminates the passing of requirements from one operator to another. As the response of the machine to the calling signal is normally immediate, the saving in service time is considerable. The possibility of an error in transmitting the information is transferred from the human element to the machine, and one operator is eliminated from all but a small proportion of calls, so that operating expenses at the incoming end are avoided by the provision of the additional plant to permit dialling in addition to signalling over the long-distance circuit. The necessary apparatus is not extensive as the voice-frequency receiver must be provided for automatic signalling alone.

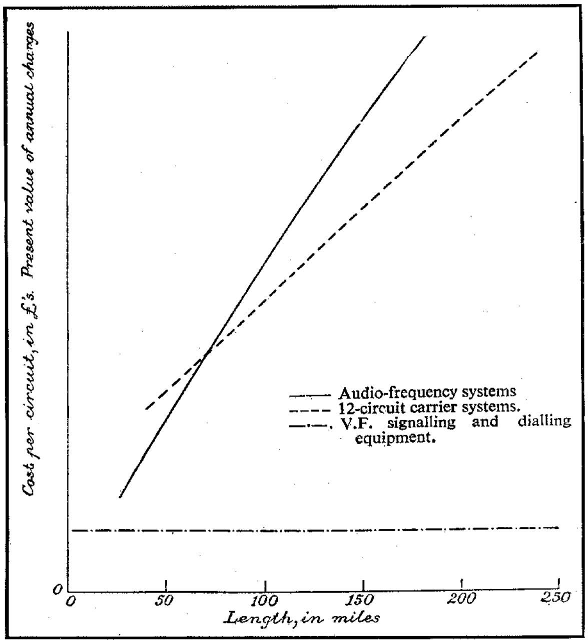


Fig. 1—Comparative Cost of V.F. Signalling and Various Cable Transmission Systems.

The conclusion is obvious that the use of automatic signalling and dialling saves line time, but it is not so easy to compare the value of the line time saved with the difference in cost between the types of equipment involved. The annual charges for the signalling and dialling equipment are almost proportional to the number of circuits equipped, the length and cost of the line having no bearing on the arrangement or complication of the apparatus. In Fig. 1 comparison is made between the cost of voice-frequency signalling and dialling equipment and that of two types of speech transmission system. The latter has been calculated for conditions in this country and on the assumption that some 300 circuits would be required at the end of a period of 20 years.

To those familiar with the average duration of the holding times of automatic switches it may seem that too much emphasis has been attached in this Section to the reduction of service operating time, but it should be appreciated that this time is often measured in minutes rather than seconds on long-distance calls and that the percentage of ineffective calls is higher than on local connections, due to the fact that the calling subscriber may be asked to leave the telephone and await a recall on account of delay, particularly on personal calls. Table I, compiled from observation records, shows operating and conversation times for demand calls for two cases. Case A is

TABLE I

AVERAGE SERVICE AND HOLDING TIMES

Type of call	Case A*	Case B†
	sec.	sec.
Service time without dialling	94	67
Service time with dialling	—	48
Add for personal calls	64	—
Conversation time (excluding service)	243	183

* British Post Office, January–June, 1939.
† La Plata–Buenos Aires, 1938.

an overall figure for a national network and includes calls with long-distance routes in tandem, while Case B relates to a single route before and after the introduction of long-distance dialling.

(2) *Reasons for the Present Use of Currents in the Voice-Frequency Range for Signalling and Dialling on Long-Distance Circuits*

(2.1) SUITABILITY OF VOICE-FREQUENCY CURRENTS FOR SIGNALLING

Whatever the means of building up a long-distance connection, all the telephone circuits involved must be capable of transmitting voice currents without undue attenuation. In this fundamental principle resides one of the main attractions of voice-frequency signalling. This does not apply to other methods of signalling, such as those utilizing direct current and low-frequency alternating current, which may be suitable for some speech transmission channels but quite unsuitable for others. Fig. 2 shows an example of a built-up connection between the towns A and E. The sections AB and DE are relatively short open-wire lines without amplifiers and are suitable for d.c. signalling. The section BC is operated at audio frequencies, but on a 4-wire basis, and includes amplifiers. Between C and D speech channels are provided by a multi-circuit carrier telephone system. The only frequencies which will pass conveniently over the complete circuit are those in the voice-frequency range. At the time when long-distance signalling and dialling were first being considered it was quickly appreciated that, as the signal receiver could be designed to respond faithfully to a voice-frequency signal, there should be no major difficulty on signalling over any built-up connection.[5] The possibility of developing a voice-frequency signalling and dialling system was technically attractive. The probability of the general adoption for long-distance circuits of speech transmission systems based on carrier-current principles appeared as a further reason for thinking that other methods of signalling and dialling would be less suitable.

(2.2) OTHER PRINCIPLES OF SIGNALLING OVER LONG-DISTANCE LINES

Two other principles for signalling and dialling which have been widely used employ direct current and 50-c./s. alternating current respectively.

(2.2.1) *Direct Current*

A loop resistance of 1,500 ohms approaches the limit over which the simplest method of direct-current dialling can operate. With this arrangement the outgoing end comprises impulsing contacts in series with the line. At the incoming end an impulsing relay is connected in series with the battery. Line leakage tends to short-circuit the impulsing contacts and some improvement is possible with "battery dialling." With this method dialling is frequently over an earth-return path; the battery and impulsing contacts are in series at the outgoing end.

When there are two or more repetitions of impulses the distortions may still be too great to ensure reliable operation without the aid of impulse correctors or impulse regenerators. The former avoid extremes of impulse ratio and the latter are devices which receive, store and retransmit impulses. These additions, whether they are regarded as improvements or palliatives, are all responsible for an increase in annual charges, on account both of first cost and of increased difficulty of maintenance. A rough comparison (Fig. 3) may be made with voice-frequency signalling, which remains at a fixed charge irrespective of distance.

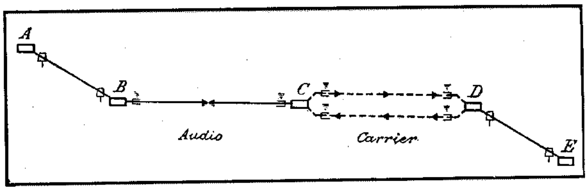


Fig. 2—Typical Built-Up Long-Distance Connection.

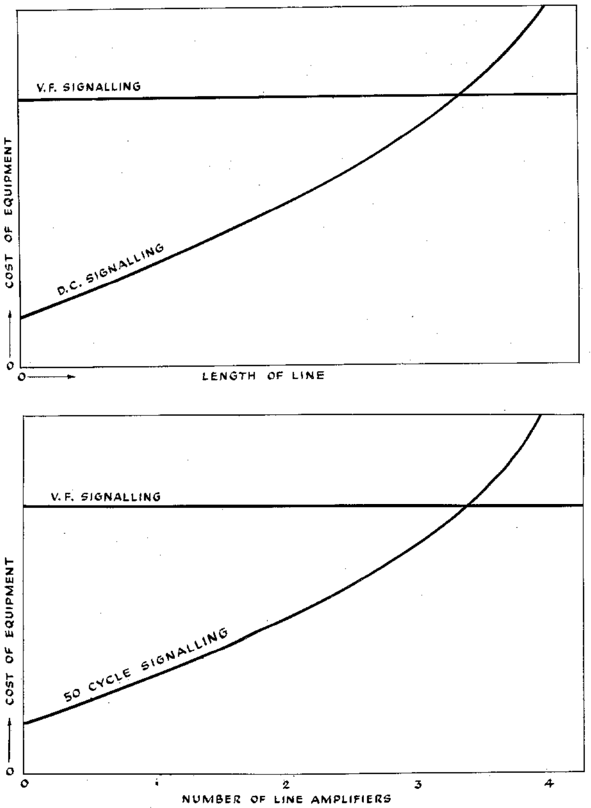


Fig. 3} *Fig. 4*}—*Comparison of Annual Cost of D.C. 50-c./s., and V.F. Signalling Systems.*

Note: The point at which the 2 curves cross in each case will vary considerably according to the facilities provided.

The ingenuity and effort which have been spent in the development of long-distance direct-current signalling and dialling may be appreciated from a study of a system[14] recently designed by the Post Office for restricted application. This system was intended for operation over lines equivalent to 100 miles of 20-lb. star quad phantom circuit. A direct-current loop path is essential. At the incoming end a receiver is connected to the line temporarily for the receipt of impulses by a prefix signal. Transmission of this signal is controlled by a regenerator at the outgoing end which also serves to narrow the transmitted impulse limits. Line equalization over the essential frequency range is obtained by terminating the line in a suitable transformer. The beginning and end of each impulse are marked respectively by positive and negative voltage surges which vary the potential on the grid of a valve controlling a telegraph type relay in order to provide a corresponding direct-current signal. Although this system is likely to prove valuable in providing dialling and signalling facilities over certain loaded circuits, it is not applicable to those on which no direct-current path is available, owing to the phantom being otherwise employed, or to those operated by carrier or radio frequencies.

(2.2.2) *50-c./s. Alternating Current*

Extensive use of a 50-c./s. signalling and dialling system indicates that such a system also has an important field. No loop path is required. The fact that all the necessary signals pass over the two wires forming the speech path without the use of direct current is of importance because it implies that 50-c./s. signals can be employed for both side circuits and phantoms simultaneously. This would be of no advantage with star quad cables on which the phantom circuits are generally useless for speech purposes, but the advantage of using the phantom in open-wire lines or other types of cable is important. One modern 50 c./s. system transmits with no more than 16 volts and uses a telegraph type relay to respond. The relay is probably sufficiently sensitive to receive satisfactorily signals that have passed through a line amplifier, although 50 c./s. is below the frequency band at which transmission can take place without serious loss. It is the practice, however, to fit a 50-c./s. repeater, arranged to pass currents around the line amplifier in either direction. The cost of 50-c./s. systems is, therefore, in part dependent on the number of line amplifiers; a consideration which does not affect the cost of voice-frequency equipment (see Fig. 4).

It is apparent that with 50-c./s. systems the response of the receiving relay is partly dependent on the phase of the supply at the time when the impulse is generated. It should be noted that this circumstance may be more important on systems in which impulses may be subjected to the variations of the subscriber's dial and may be distorted by the telephone circuit, than in systems using machine-generated impulses closely controlled for ratio and speed. The phase mutilation may take place not only on generation of the 50-c./s. current but also at each repetition. However, the portion of the cycle at which the voltage is insufficient is relatively small and, even with all conditions adverse, it is possible to impulse through more 50-c./s. repetitions than are likely to be found in any built-up connection. Public supply systems provide a ready source of signalling current. 50-c./s. signalling and dialling is likely to be cheaper than d.c. methods or voice-frequency for long-distance circuits, but existing carrier systems do not transmit this frequency.[7]

Dialling and signalling between zone centres has been exploited further in Switzerland than perhaps in any other country.[16] It is probable that the geographical arrangement of the country is an influential factor because the principal central switching points at Berne and Zürich are so placed that the average distance of through long-distance circuits is scarcely more than 50 miles, and, in consequence, there are relatively few circuits on which multi-channel carrier systems are installed. The conditions in Switzerland are generally suitable for 50-c./s. operation, and the decision of the Administration to adopt the 50-c./s. equipment was presumably partly due to the economy obtained by using both physical and phantom circuits. This decision has been justified by the service which has been provided during the last 7 or 8 years. 50-c./s. signalling and dialling has also been used for many years in Norway, Hungary and Czechoslovakia, but the greater mileage between centres in these countries makes it appear unlikely that the system can find universal application for long-distance circuits.

(2.2.3) *500- and 2,500-c./s. Alternating Current*

500-c./s. currents have been used for signalling and dialling in a number of countries, particularly in Germany and France, and 2,500-c./s. currents have been used in the Netherlands. These systems can be classed with the voice-frequency systems using 600- and 750-c./s. currents, because the frequencies used fall within the speech band and, therefore, such currents are suitable for use with most speech transmission systems. As will be seen from Section (4), the C.C.I.F. have made various recommendations for the protection of voice-frequency signalling systems from incorrect operation due to extraneous current. These safeguards apply only to 600 and 750 c./s. which are reserved for signalling and dialling, and it would seem that little purpose can be served in contemplating any other frequencies in the audio range.

(2.3) LINE CONDITIONS

Having established that there are good reasons for the adoption of automatic signalling and dialling facilities on long-distance circuits, it becomes apparent on investigation that the requirements may be provided in several ways. The line conditions may be expected to influence decisions as to the most suitable arrangement, and it is desirable to review in general terms the constitution of long-distance circuits. As the length of line and number of circuits increase, the use of carrier transmission systems becomes more economical than separate audio circuits. Several separate carrier systems on the same route may in turn be replaced by multi-channel systems, providing a very large number of channels over

TABLE II

DISTANCES BETWEEN REPRESENTATIVE SWITCHING CENTRES

Country	Switching centres	Distance
		miles
AUSTRALIA	Sydney — Adelaide	850
	Sydney — Brisbane	500
	Brisbane — Melbourne	1,000
	Sydney — Melbourne	500
	Adelaide — Perth	1,500
	Hobart — Melbourne	400
FRANCE	Bordeaux — Marseilles	330
	Paris — Bordeaux	310
	Strasbourg — Marseilles	400
	Lyons — Bordeaux	280
	Strasbourg — Bordeaux	500
	Lyons — Marseilles	180
GREAT BRITAIN	London — Birmingham	120
	London — Manchester	200
	Leeds — Glasgow	200
	Manchester — Belfast	200
	London — Glasgow	400
	Manchester — Leeds	40
THE NETHERLANDS	Rotterdam — Eindhoven	60
	Amsterdam — Breda	50
	Leeuwarden — Amsterdam	65
	Rotterdam — Arnhem	60
	Maastricht — Groningen	170
	Harlem — Amsterdam	10
RUMANIA	Bukarest — Cluj	220
	Bukarest — Cernauti	260
	Bukarest — Jasi	200
	Timisoura — Chisinau	380
	Braila — Brasov	100
U. S. A.	Los Angeles — Dallas	1,250
	Atlanta — Denver	1,060
	New York — Dallas	1,400
	New York — Chicago	750
	New York — San Francisco	2,550
	Chicago — St. Louis	260

pair- or coaxial-type cable. It is clear that the ratio between the cost of the speech circuit and the cost of the signalling equipment in countries such as the U.S.A.,[1] U.S.S.R., Australia, Canada and South Africa, is very different from the corresponding ratio in the Netherlands, Belgium and Switzerland. Table II shows some typical distances between main switching centres of various Administrations.

The picture is not complete with such a summary of transmission systems, even when allowance is made for the various types of system of the same class, because circuits between adjacent switching centres will not always be of any one type from end to end. In times of emergency extensive patching may be necessary by quite roundabout routes. It would be a considerable restriction to the general arrangement of long-distance lines if the patching depended to any extent on the type of terminal equipment installed.

(2.4) IMPULSING CONDITIONS

Some consideration must also be given to the fundamental switching layout, particularly as regards the repetition of impulses. Most of the permissible distortion is absorbed in switching calls from end to end of a local area. This is roughly equivalent to admitting half the permissible distortion from the subscriber to the group centre. A similar loss may occur in the reverse direction from the group centre to the most distant subscriber and, in consequence, little, if anything, is available for any long-distance line joining the group centres. In register-controlled systems each area is provided with a separate permissible distortion measured from the register itself. In recent years impulse regenerators have been introduced to nonregister systems, performing a similar function to that of the registers, because by their use the subscribers can be isolated from the long-distance line.

An analogy is possible with the design of the corresponding transmission system. In most countries nearly all permissible speech attenuation and distortion from subscriber to subscriber may occur in a local area, and very little is left for the long-distance circuit. Long-distance circuits may, however, be so engineered that the speech impairment is very small. Most designers have accepted the principle that impulsing over the voice-frequency circuit should be achieved with negligible distortion by inter-operation with registers or regenerators.

(2.5) CONCLUSIONS AS TO PRESENT USE OF VOICE-FREQUENCY SIGNALLING AND DIALLING

In Section (3) reference is made to the extent to which regenerators may be used to eliminate possibilities of interference. The restrictions and conditions which the v.f. receiver and the associated code of signals have to face result in an accumulation of protective arrangements needing apparatus and wiring. In consequence the receiving and transmitting relay sets are more expensive than those required for direct current or alternating current at 50 c./s., and this is undoubtedly largely due to the intention to use the voice-frequency equipment for different conditions. Nevertheless, an administration operating a long-distance network of lines chiefly comprising multi-channel carrier systems would feel justified in standardizing the use of voice-frequency signalling and dialling, whereas another administration operating a smaller percentage of carrier circuits might feel justified in using two different systems in the interest of economy in first cost.

The use of voice-frequency currents for signalling and dialling over long-distance circuits has already been introduced in Great Britain,[6] Germany, Eire and large districts of Australia.[17] To a more limited extent it has been used in the Netherlands, Belgium, Italy and Hungary.

(3) *Technical Problems Involved in the Design of Voice-Frequency Signalling Systems*

(3.1) INTRODUCTION

Realization of a voice-frequency signalling system necessitates provision of a group of relays for connecting the voice-frequency current to the line in response to d.c. signals. In addition, a signal receiver is required for the subsequent translation of the voice-frequency line current to d.c. signals. Many problems in telecommunication engineering arise. Their solution is influenced by the following factors:—

(*a*) The facilities required for setting up, supervising and clearing a call.

(*b*) The complications arising from connection to the speech circuit of apparatus, such as echo-suppressors, not associated with signalling.

(*c*) The performance that can be obtained from the voice-frequency signal receiver.

The voice-frequency signal receiver (v.f. receiver) must discriminate currents which represent signals from those of the same frequency due to speech sounds or line noise. The difficulties encountered in doing this lead to the definition of two terms, *signal imitation* and *signal interference* "Signal imitation" describes false operation of the v.f. receiver by a component, or components, in speech or noise of the frequency, or frequencies, used for the transmission of genuine signals. As will be seen later, certain steps are taken to minimize the chance of this happening. In turn these steps may prevent the receiver responding to genuine signals when speech or noise is present. This is known as "signal interference." Designers seek to find a compromise between signal imitation and signal interference.

Voice-frequency systems have not been designed for simultaneous signalling in both directions, but circuit conditions may result in an attempt to pass signals in opposite directions at the same instant. If this happens the operation of echo-suppressors may spoil the passage of the signals. Echo-suppressors are essential features of some types of modern high-grade long-distance circuits and permit only one-way transmission at a time. They may be operated against the signal by speech, tones or signals in the reverse direction.

Further complications arise on built-up connections. These are due to the fact that signals intended for operation within one section may pass to a second section and there cause unwanted switching operations.

Automatic telephone exchanges in Great Britain utilize switching equipment of the Strowger (step-by-step) type. With this type of equpiment the pulses of current used to position selecting switches must correspond closely to the pulses generated by the originating dial. This must be true after they have been transmitted over the line and subsequently translated from alternating to direct current by the v.f. receiver. Somewhat greater distortion is permissible if the exchange equipment is of the register type.

It will be useful to set out the problems referred to above and to indicate solutions before considering each problem and its solution in greater detail. All of these contribute towards the expense and complication which are to some degree inherent in voice-frequency signalling and dialling systems.

(3.1.1) *Signal Imitation*

Since currents at the signalling frequencies also occur in speech, some protection must be provided to avoid false operation of the v.f. receiver. Protection may be obtained by the use of:—

(*a*) Voltage limiter in the receiver.
(*b*) Guard circuit in the receiver (relay or grid-bias type).
(*c*) Signals exceeding a specified duration.

(3.1.2) *Signal Interference*

Precautionary devices necessary to guard against signal imitation may be operated by speech or tone present at the same time as signals, thus giving rise to signal interference. Interference due to currents having their origin at the same end of the line as the v.f. receiver can be reduced by means of a hybrid connection.

(3.1.3) *Interference due to Echo-Suppressors*

Some long-distance lines are fitted with echo-suppressors, which are liable to prevent transmission of voice-frequency signals. This obstacle may be overcome in various ways, of which one is the repetition of signals until their receipt is confirmed by an acknowledgment signal.

(3.1.4) *Inter-System Interference*

When two similar and adjacent voice-frequency signalling systems are associated in a connection, signals may be passed from end to end to avoid the delay and distortion caused by repetition. If, however, this is impossible because there is an intervening link in the connection with some other means of signalling, or because the signalling codes are different, signals from one system entering the second will cause interference. Confusion from this source is avoided by the use of a "prefix" signal and a line-splitting technique which depends on rather accurate timing for its successful operation.

(3.1.5) *Impulse Distortion*

The duration of the dialling impulse normally used is of the order of 60 millisec., and the period between impulses is somewhat smaller. The response time of the v.f. receiver is 10 millisec. or more. In order to maintain the impulse response as accurately as possible, it is desirable to use one frequency only and make the receiver as quick as possible in its response to this frequency.

The solution of these problems lies partly in the design of the v.f. receiver, partly in the design of the signalling system as a whole, and to a great extent in the choice of the signal code.

Related to the signal code it may be useful to define two types of signal element:

(3.1.6) *Simple Signals*

Pulses consisting of either signalling frequency alone are known as simple signals.

(3.1.7) *Compound Signals*

Pulses comprising both signalling frequencies simultaneously are known as compound signals.

(3.2) OPERATING REQUIREMENTS TO BE MET

(3.2.1) *Signalling*

The facilities required vary in different countries. Those regarded as essential usually include the ability (*a*) to seize a circuit and distant terminal equipment, (*b*) to transmit dialling impulses, (*c*) to give information that the called subscriber has answered, (*d*) to give information that the call may be cleared, and finally, (*e*) to transmit a signal to cause the complete release of the circuit and associated apparatus at both ends. Other facilities may be required, and a system should be capable of giving them.

Systems which enable a subscriber to set up a local call by dialling vary considerably in layout and design, but there are certain fundamental principles which are common to all systems and countries. Briefly, these consist of calling by forming a loop of the two line conductors, thus allowing current to flow, dialling by momentary interruptions of this loop, thus generating pulses of direct current which serve to position the selecting switches, and clearing by permanently breaking the loop. It is impossible to model the v.f. system on such principles, as there are many reasons why the audible signalling current should not be applied for long periods. All information must, therefore, be conveyed by coded pulses of the signalling frequency and more apparatus is required. This arrangement also constitutes a slower method of communication than the change-of-condition method used in d.c. circuits. Signal discrimination may be effected by variation of the frequency of the signalling current, of the duration or number of pulses, or by a combination of these variations.

Simultaneous passage of forward and backward signals is often impossible. If a signalling condition, notified from one end by sending a succession of pulses, is to be acknowledged from the other end, adequate intervals must be provided between pulses to permit the transmission of the acknowledgment signal in the reverse direction. This interval is fixed as about 550 millisec. by a combination of factors—the propagation time of the circuit, the change-over time of the echo-suppressor, the response time of v.f. receivers, the time necessary for the recognition of a signal, and various relay release times.

(3.2.2) *Dialling*

The economic advantages to be gained from automatic signalling over long-distance circuits are only fully realized if, in addition to providing for the quick and accurate transmission of change-of-circuit information, the system also enables dial signals to be transmitted with sufficient accuracy to actuate correctly distant automatic switching equipment. Selectors in a step-by-step system will generally respond to impulses at speeds between 9 and 11 impulses per sec. having make/break ratios between 1 : 1 and 1 : 4. Somewhat wider variations are permissible to the impulses which serve to set the switches in a register system. In both cases the tolerances will, to a large extent, be absorbed by variations in operators' dials and by distortion introduced during a number of repetitions when the connection involves several links in tandem, as already indicated in Section (2.4).

(3.3) RECEIVER DESIGN

(3.3.1) *General*

Development and introduction of voice-frequency signalling and dialling have largely awaited the solution of technical difficulties in the design of the v.f. receiver. As a measure of the success that has been achieved, it can be stated that few of the early troubles experienced with the systems now working were due to the receiver.

The initial problem results from the fact that, in order that the v.f. receiver may be ready for the release and other signals, it has to remain permanently bridged across the line when this is being used for conversation. In addition to genuine signals, therefore, it has applied to its terminals speech and noise currents which may contain components at the frequencies used for signalling. To a certain extent currents having their origin on the local side of the receiver may be avoided by insertion of a hybrid transformer between the line and the v.f. receiver. Fig. 5 shows the arrangement of an unequal ratio differential transformer with a balancing network *Z* having an impedance which is higher than that of the line. This permits the v.f. receiver to be connected with quite a low loss. Currents approaching the transformer from the direction of the local exchange divide unequally between *Z* and the line and only have an effect on the secondary windings connected to the v.f. receiver due to imperfection of the balance. On the other hand, currents incoming from the line flow through the primary half-windings in such a direction that their inductive effects on the secondary windings are additive. No discrimination by the hybrid transformer is possible between wanted and unwanted currents incoming from the long-distance line.

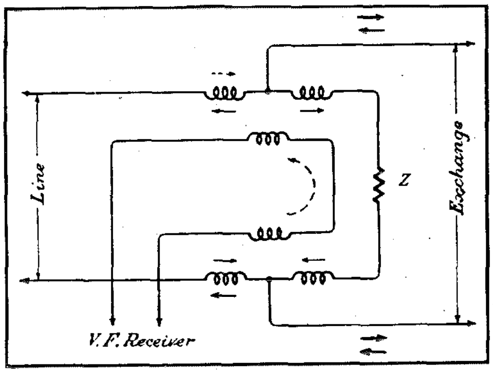


Fig. 5—Principles of Hybrid Transformer Connection.
Currents having their origin on the exchange side.—→
Currents having their origin on the line side.- - →

A power of the order of 1 or 2 mW, measured at a point of zero relative level, is usually employed for the transmission of signals, although in order to prevent the over-loading of amplifiers on multi-channel carrier telephone systems it is necessary in some cases to reduce the power when repeated signals are transmitted. Although only small attenuation is to be expected as a result of transmission over a long-distance line directly connecting zone centres, the level of signals received over different built-up connections may vary considerably. Such considerations lead to anticipated variations in the received signal voltage of 22 db., i.e., approximately a 12 : 1 ratio. In order to facilitate design of later stages in which d.c. signalling relays are operated by rectification of the voice-frequency currents, an early stage of the receiver may take the form of a voltage limiter. The output voltage from the limiter stage remains sensibly constant for a wide range of input voltage.

The frequency of received signals may be inaccurate, due either to incorrect speed of the frequency generators at the distant terminals or to actual change of frequency during transmission over one or more sections of a particular long-distance circuit operated by carrier telephony where the modulating and demodulating carrier frequencies are not synchronized. Some allowance for commercial tolerances in the components which are used in building up the signal-selecting elements is necessary. A band-width of ±22.5 c./s. is considered adequate for all these purposes.

As the v.f. receiver must remain permanently connected to the line, its input impedance must be sufficiently high to avoid causing appreciable loss to speech or other transmission. Such loss is usually kept below 0.25 db.

(3.3.2) *Prevention of Signal Imitation*

There is no single characteristic which can be used to distinguish signals from speech and noise. Contemporary design[8] relies on some or all of the following principles:

(i) Tuning the v.f. receiver so that it is more responsive to the signal frequencies.

(ii) Preventing response of the receiver to signal frequencies if other frequencies are present; this may be done in one of two ways:

(ii*a*) By the selection of specific non-signal frequencies to impose an electrical or mechanical guard on the receiver.

(ii*b*) By passing the total input from the line initially through a limiter stage and then making response of the receiver depend on the receipt at its later stages of signal frequency exceeding a predetermined level.

(iii) Imposing time delays.

Attempts have been made to use such distinguishing features as the varying amplitude of speech from moment to moment, but so far no successful design has been evolved. The design of early systems was assisted by the use of greater signal powers than those permissible at present.

Simple resonant circuits to increase the response of the v.f. receiver to the signal frequencies are generally included. The sharpness of tuning depends on a variety of factors, but, as already indicated, the band-width over which sensibly uniform performance is obtained should extend for at least 22.5 c./s. on each side of the nominal signalling frequency.

Use of frequencies other than those adopted for signalling to apply some degree of guard to prevent response of the v.f. receiver is general. Band-stop filters, tuned to the signalling frequencies, are sometimes employed so that the v.f. receiver is effectively made unresponsive should voltages at any frequency differing appreciably from the signalling frequencies be applied to it. Other designers rely on the presence of components at one or more selected frequencies, and the first sub-multiples of the signalling frequencies, i.e., 300 and 375 c./s., may be chosen for reasons which will become apparent later. The choice is useful, as frequencies of this order represent a considerable proportion of the power in voiced speech and also cover many components of the supervisory tones in use in automatic telephony. Whatever the frequencies selected to exercise the guarding function, the voltages in question are amplified and rectified and may then be used to operate a relay, or relays, which render simultaneous operation of other relays by components at the signalling frequencies ineffective, or they may be applied as a disabling negative bias to the grids of valves used for amplifying and/or rectifying components at the signalling frequencies.

Limitation of the voltage passed to the relay operating stages in the receiver assists in preventing speech or other currents containing both signal and non-signal frequencies giving rise to spurious signals. If the sensitivity of the later stages is set so that a voltage at the signalling frequency only just below the full output of the limiter is required for operation, this will not be available when the input voltage contains other components of considerable magnitude.

Nearly all limiting devices produce harmonic distortion of the limited voltage wave. Although ingenious methods have been devised for compensating such distortion by means of wave-form shaping circuits, generation of harmonics by the signalling frequencies and of the signalling frequencies by their sub-harmonics usually occurs. Generation of these components in the limiter stage may influence the choice of non-signal frequencies for guarding the receiver against false operation.

The properties of a limiter add further difficulty to the design of a v.f. receiver which has to respond to compound as well as to simple signal components. With compound signals the available power, determined by the limiter, is divided between two relays. It is therefore restricted in each relay to a smaller value than it has when there is one signalling frequency alone. In addition, as the limiter usually has non-linear characteristics it gives rise to modulation products when passing compound signals. These may be troublesome.

False operation of the v.f. receiver can be rendered ineffective by interposing a time delay between the first reception of current at a signalling frequency and any resulting change of condition in the d.c. circuits controlled by the receiver. If the delay is sufficient, signal imitation can be eliminated almost entirely but the speed of signalling is made slower. The delay is provided by relays.

(3.3.3) *Prevention of Signal Interference*

Application of some of the means of preventing signal imitation just described may render abortive any attempt to signal while speech or tones are being transmitted over the circuit. If signals have to be received in these circumstances any electrical or mechanical guard preventing effective response of the receiver must not operate with a time lag so long that the inhibiting condition will persist throughout pauses in the speech or tones. Further limitation of the effect of the guarding arrangements may become necessary as, in whatever way unwanted operation of the receiver is prevented, the insensitive condition must not occur or persist due to room noise transmitted through the subscriber's microphone or to reasonable amounts of line noise.

(3.3.4) *Reception of Dialled Impulses*

In addition to any added delay which may be introduced to prevent signal imitation, the v.f. receiver itself requires a response time which may be of the order of 10 or 12 millisec. It has already been pointed out that dialling impulses must be converted from voice-frequency to direct current with the minimum added distortion. This makes a short receiver-response time desirable. It is usual to arrange that guards, such as those provided by the addition of time delays, become inoperative when the receiver is in a dialling condition. Relay operations reimpose the guards during periods when the circuit is open to conversation, as otherwise occurrence of the dialling frequency in speech would cause undesirable clicks.

The desirability of the v.f. receiver response time being the minimum possible leads to the invariable use of pulses comprising one signalling frequency only for dialling, as all the power passed by a limiter stage is then available in one relay-operating stage.

If the quality (ratio of reactance to resistance) of tuned signal acceptor circuits is high, frequencies just outside the nominal pass-band will be effectively prevented from causing false operation of the receiver. On the other hand, the higher the quality of the tuned circuit the more slowly will an accepted pulse of current at the impulsing frequency build up to its final value, and it will become difficult to avoid the introduction of impulse distortion.

(3.3.5) *Design Details*

It is not the purpose of this paper to describe any particular design of v.f. receiver for voice-frequency signalling. Fig. 6 indicates in schematic form the principles of four receivers in fairly extensive use. The first and second of these are employed in connection with systems making use of simple signals only. The third and fourth will operate to compound as well as to simple signals. The receivers are mounted on jack-in type baseplates commonly used for automatic telephone switching equipment.

(3.4) SYSTEM DESIGN

(3.4.1) *Interference due to Other Signals, Speech or Non-Signalling Currents*

Signalling becomes more difficult after the connection of supervisory tones or the commencement of speech. Echo-suppressors, if connected to the circuit, may be operated by speech or tones transmitted in the opposite direction to that in which it is desired to signal and bar the signal path. The distant v.f. receiver may be adversely affected by noise or speech and rendered insensitive to genuine signals. Solutions to these problems have been developed in one or other of the following ways:

(i) By repeating signals until their correct reception at the far end of the circuit is acknowledged by a signal sent in the reverse direction.

(ii) By the transmission of pulse signals, stopped only as a result of a further change in the circuit conditions.

(iii) By temporary alteration to the circuit so that access of interfering currents from their most likely source is prevented.

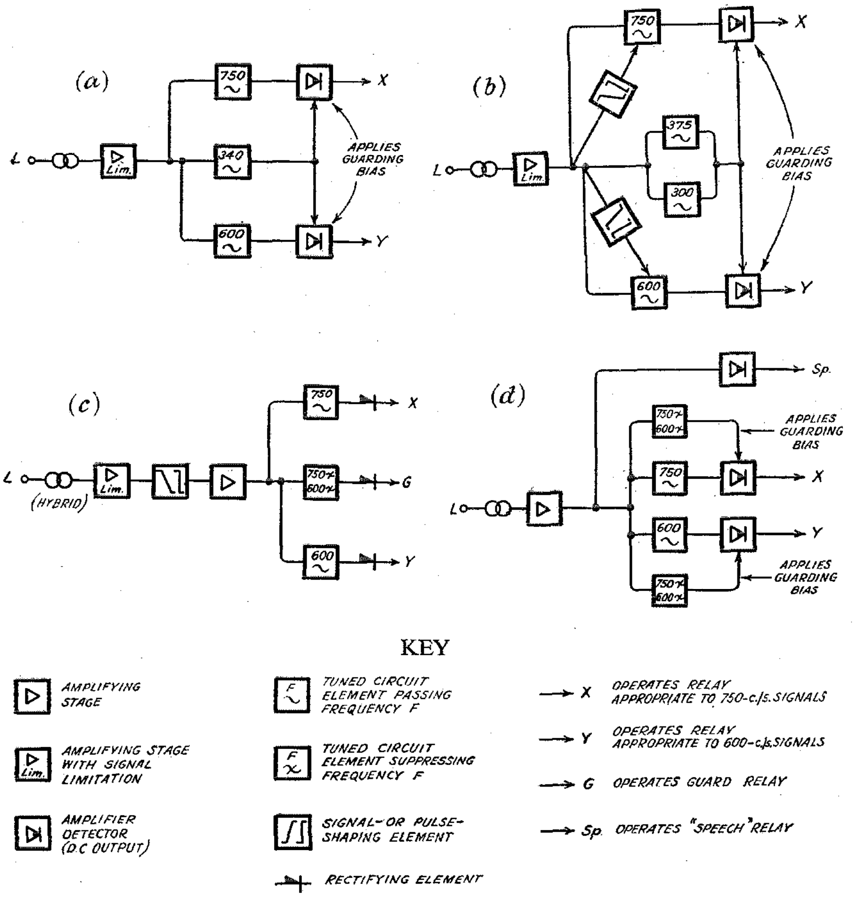
(iv) By testing at the outgoing end for other voice-frequency currents and, if the reception of these indicates that signal interference will be encountered,

(iv*a*) Repeating signals.

(iv*b*) Delaying the transmission of signals.

As an example of the first type of solution, it is necessary to ensure that the forward clearing signal will reach the distant end in spite of echo-suppressors operated by speech in the reverse direction. This is done by repeating signals, separated by adequate pauses, until an acknowledgment signal is received in the backward direction.

The second type of solution, which is somewhat similar to the first, may be illustrated by a particular means of dealing with supervisory signals transmitted from the called subscriber. When this subscriber hangs up, a signal must be sent back to indicate that he has done so. Con-


(a)
L
Lim.
750
340
600
X
Y
APPLIES GUARDING BIAS
(b)
L
Lim.
750
375
300
600
X
Y
APPLIES GUARDING BIAS
(c)
L
(HYBRID)
Lim.
750
750+600
600
X
G
Y
(d)
L
Sp.
750+600
750
600
750+600
APPLIES GUARDING BIAS
X
Y
APPLIES GUARDING BIAS
KEY
AMPLIFYING STAGE
AMPLIFYING STAGE WITH SIGNAL LIMITATION
AMPLIFIER DETECTOR (D.C OUTPUT)
TUNED CIRCUIT ELEMENT PASSING FREQUENCY F
TUNED CIRCUIT ELEMENT SUPPRESSING FREQUENCY F
SIGNAL- OR PULSE-SHAPING ELEMENT
RECTIFYING ELEMENT
X OPERATES RELAY APPROPRIATE TO 750-c/s. SIGNALS
Y OPERATES RELAY APPROPRIATE TO 600-c/s. SIGNALS
G OPERATES GUARD RELAY
Sp. OPERATES "SPEECH" RELAY

Principles of typical v.f. receivers.

Fig. 6—Principles of Typical V.F. Receivers

(a) 50-V Supply *(b) 50-V Supply*
(c) 130-V and 21-V Supplies *(d) 220-V and 12-V Supplies*

tinual repetition ensures that a signal is successfully received in spite of interference. Cessation of the signals may be brought about by the called subscriber returning to the line or by complete release of the connection, the latter condition being the result of a signal transmitted in the forward direction and operative in the intervals between repetitions of the signals being sent in the backward direction.

Use of a distinctive answer signal indicating that the called subscriber has come on to the line is a feature of the operating procedure in some countries. The steps taken in the British Post Office system to safeguard this signal from loss when it is sent in face of such interference as noise currents generated in the subscriber's or operator's transmitter, speech, further dialling, or switch-hook flashing from the calling end, indicate the third type of solution. An answer signal long enough to exceed in duration such interference is undesirable because of the delay which it would introduce before the commencement of conversation. The difficulty is overcome by the insertion, until the called subscriber answers, of a one-way repeater at the controlling exchange. This repeater enables supervisory tones to be heard by the controlling operator but prevents local disturbance at the calling end from passing out on to the line. The one-way repeater is cut out and the circuit automatically made available for two-way conversation on reception of the answer signal.

The means adopted in Great Britain are not readily applicable in all countries because no speech is possible until the answer signal is given, and with some systems this must be withheld until it is known that the required party is available. The signalling system in use in Eire retains the one-way repeater, but does not necessitate an answer signal, as the circuit is automatically made available for speech when dialling is concluded.

Reference will be made later to the one-way repeater as a means of safeguarding dialling impulses against interference. As the introduction of such a repeater is not uncommon, its uses in a v.f. signalling system may be set down as:

(*a*) To prevent interference to signals from speech, transmitted in the reverse direction.

(*b*) To prevent the v.f. receiver being rendered inoperative by surges generated in a d.c. circuit [Section (3.4.1.1)].

(*c*) A means of protecting the v.f. receiver when it is in a highly sensitive condition for such purposes as the reception of dialling impulses [Section (3.3.4)].

Solutions depending on a test of the circuit for interference listed above as (iv*a*) and (iv*b*) are obtained by means of a "speech" relay connected to the return path of a 4-wire line. The arrangement depends on the introduction of a relay which has a similar sensitivity-frequency characteristic to the echo-suppressor, with sufficient sensitivity to operate before the echo-suppressor but insufficient to operate to line noise. If the speech relay is operated by line currents, transmission of signals is either repeated or delayed. This method is used in Germany to overcome jamming of signals by intermediate echo-suppressors; terminal echo-suppressors are so arranged as to be incapable of causing interference.

Interference caused by terminal echo-suppressors may be avoided if the voice-frequency signalling equipment is connected to the 4-wire portion of the long-distance line. The German system is designed on this principle. Arguments in favour of its use are discussed in Section (5.4).

(3.4.1.1) *The Special Case of Interference to Dialling Impulses*

Various oscillograms illustrating effects which have to be overcome in order that dialling impulses may be transmitted without harmful distortion have been assembled in Fig. 7. In this figure, *a* shows the form of a typical d.c. pulse applied to the relay which controls the application of the voice-frequency voltage to the line. The non-rectangular shape is due to the nature of the local d.c. circuit and must be accepted as an initial disability. Fortunately, dialling impulses are usually transmitted when the line is free from speech or jamming by noise. Superimposed surges, generated in the d.c. part of the circuit and transmitted over the speaking wires, may, however, be troublesome. A typical surge is shown by *b* in Fig. 7. The surge voltage may render the v.f. receiver at the distant end of the line insensitive and prevent its proper response to the subsequent pulse of voice-frequency current and, at the outgoing end, the sequence of operations is such that it is difficult to avoid transmitting forward this surge voltage.

There are various methods of tackling this difficulty. Systems provided with a distinctive "end of selection" signal can be arranged to isolate the outgoing circuit and to connect it for forward speech only when dialling is completed. Conversely, use could be made of a preparatory signal preceding each train of dialling impulses. Insertion of a one-way repeater, previously referred to as the means used in Great Britain of preventing interference with the answer signal, is an effective remedy; so is control of the circuit by means of the German "speech" relay, also mentioned in Subsection (3.4.1). The forward path of the 4-wire line is disconnected from the d.c. impulsing circuit when dialling is taking place and is connected through as a result of operation of the relay by speech or supervisory tones. Use of the dial contacts to control the voice-frequency current, thus eliminating a d.c. to v.f. conversion, or use of a dial key so that the operator controls the disconnection and connection of the speech path, are attractive solutions. Their chief objection lies in the limitations which they impose on the building-up of circuits, since they preclude the possibility of having a d.c. link in front of a voice-frequency link, and this may be a normal requirement. Such solutions would also be unsuitable for subscriber dialling. The use of a regenerator is effective because the delay between pulsing the d.c. impulses into the regenerator and the regenerator pulsing out the corresponding voice-frequency impulses allows the effects of the initial surges to die away before v.f. impulsing commences.

At the incoming end, stepping of the selectors, accomplished by impulsing on the speaking wires, is again productive of surges in the speech and signal path. The introduction of a regenerator is effective as at the outgoing end or, since each surge follows a relay operation, surges may be suppressed from the v.f. receiver by the contacts of a fast relay. Their effect on the receiver may also be reduced by the use of a hybrid connection between the v.f. receiver and the line.

Although noise or other interfering currents may not cause echo-suppressors to bar the transmission path against a train of dialling impulses, the wave-front of the first pulse in the train may encounter a suppressor which is in an intermediate condition. Signalling current will enter the control path of the suppressor and make the transmission path available but, while this is taking place, the initial cycles of the signalling frequency will be suppressed or transmitted forward with considerable attenuation as shown by *d* in Fig. 7. Delay while the transmission path is made available is not so serious with other signals and is also comparatively unimportant during conversation, as clipping of as much as 50 millisec. from initial syllables passes unnoticed. Echo-suppressors located at an intermediate point in the circuit and in poor adjustment have been known to cause trouble due to a backward reflection of the signal from a distant termination competing for control of the suppressor with the forward signal. Partial suppression of the latter may occur temporarily, giving the "waisting" effect shown by *c* in Fig. 7. Terminal echo-suppressors may remain operated in such a way that the required outgoing signal transmission path cannot be established. This occurs when the outgoing signal immediately follows an incoming signal—a condition which does not arise during dialling but which may arise when the connection is being cleared down. The difficulty can be overcome in a straightforward manner by bringing the echo-suppressors under the control of the signalling equipment or by delaying transmission of the signal.

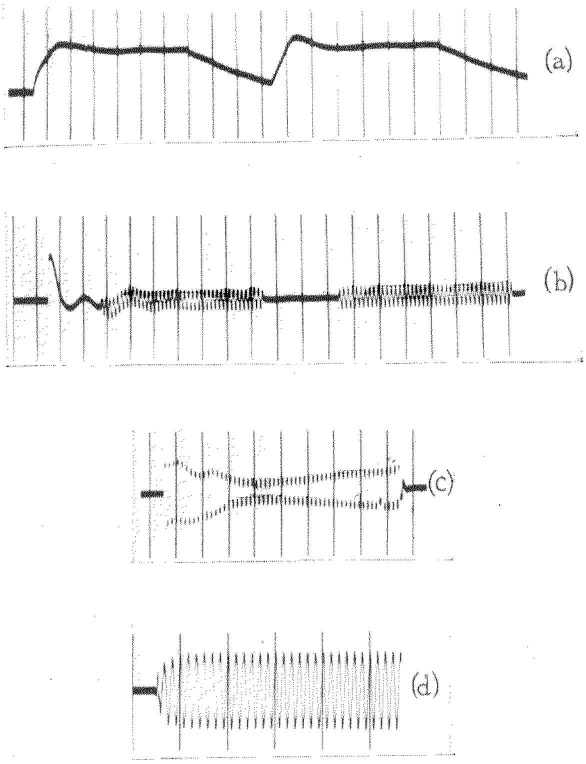


Fig. 7—Oscillograms of Signalling Pulses.

(*a*) *Direct current in relay controlling transmission of v.f. dialling impulses.*
(*b*) *Surge transmitted in advance of a train of v.f. dialling impulses.*
(*c*) *"Waisting" of a v.f. pulse due to partial operation of an intermediate echo suppressor.*
(*d*) *"Wave-front" distortion of a v.f. pulse due to delay in opening up the transmission path.*

(*Note: Vertical timing lines mark 10-millisec. intervals.*)

(3.4.2) *Inter-System Interference.*

The problems which have already been discussed are encountered on lines whose limits are within one national boundary. Whenever two circuits with voice-frequency signalling are joined together within that boundary, signalling and dialling may be extended without retransmission. International calls may, however, have to be obtained by joining together circuits in countries where different voice-frequency signalling systems are in use. If the systems are the same in principle, but signalling codes do not coincide, end-to-end signalling is impossible, as signals will have a different meaning within the foreign network, or on the international line, from that which they have in their country of origin. If the signalling codes are identical, there is still the possibility that signals unintended for end-to-end transmission may cause one section to release prematurely or cause other confusing results. Such considerations made it evident that international agreement was required on fundamental principles of design to ensure that mutual interference between different systems would be avoided. The details of such an agreement had not been fully worked out before the outbreak of war, but it had already been decided that a solution of the problem should be sought by the restriction of the signalling currents to that portion of the line where they were intended to be effective. A similar principle exists in d.c. signalling systems in which signals are restricted to separate sections of a built-up connection by means of condensers or transformers. The two cases are, however, not strictly analogous. Since speech must circulate over the whole of the connection, voice-frequency signals will do so likewise, for it is impracticable to stop them by filtration at points where different systems are, or may be, connected in tandem. Some signal must therefore be introduced which v.f. receivers located at such points will immediately recognize. On doing so they must split the connection, thus trapping subsequent signals to their appropriate section. Such a signal has been given the name of "prefix" signal.

(3.4.2.1) *Use of the "Prefix" Signal*

Use of the "prefix" signal involves general agreement as to the length of time for which the signal must be received before the connection is split.[18] If this time is made too short, false splitting will occur frequently due to signal imitation; although in some cases it can be arranged that false operations result in no more than temporary disconnection of the circuit for a time depending on the duration of the false signal. There is no definite information as to the practical importance of short interruptions in regard to the speech performance of a circuit, but it can be said that those of less than 50 millisec. duration are of no importance. The length of the prefix signal is discussed more fully in succeeding paragraphs dealing with the choice of a signal code. It follows, however, that whatever time period is fixed for recognition of the signal before the connection is split, no pulse of signalling current exceeding this period will be allowed to pass beyond the switching point. If, therefore, durations less than this of the frequency used for splitting are not assigned to significant signals, subsequent sections of a built-up connection will be free from external false signals. The minimum duration of the same frequency, which must be recognized before any operation other than splitting takes place, must be appreciably longer.

In practice response of the v.f. receiver to pulses of signalling current has the ultimate result of operating, or releasing, relays with fixed time-lags. Timing of these relays is, however, subject to inherent variations due to their adjustment. Owing to the effects of line attenuation, incorrect signal frequency and tolerances in the tuning of acceptor elements in the v.f. receiver, some time distortion may accompany conversion from voice-frequency to d.c. pulses. Furthermore, the signal may commence when guard circuits, designed to prevent operation of the v.f. receiver by speech and noise currents, are effective and, until these currents have ceased, response to any genuine signal will be impaired. For all these reasons wide tolerances are necessary on the nominal values of the time set for splitting the line and for the recognition of a significant signal.

Assuming that voice-frequency current at the frequency used for the prefix signal should be applied to the terminals of the v.f. receiver for at least 90 millisec. before the long-distance circuit is split—which Section (3.5.2) will show to be about the minimum time to ensure freedom from false splitting—the receiver and delay elements cannot be adjusted more accurately than will ensure that the maximum period for which the frequency passes the splitting point does not exceed 135 millisec. Any function, other than opening a through connection, depending on the receipt of the prefix signal, is made to follow recognition of the frequency for a minimum period of between 150 and 210 millisec. Response of the receiver itself may, however, be delayed when the prefix signal is sent during a conversation. In order to make allowance for this, the signal frequency is usually transmitted for a period of between 250 and 350 millisec. These times are shown diagrammatically by Fig. 8.

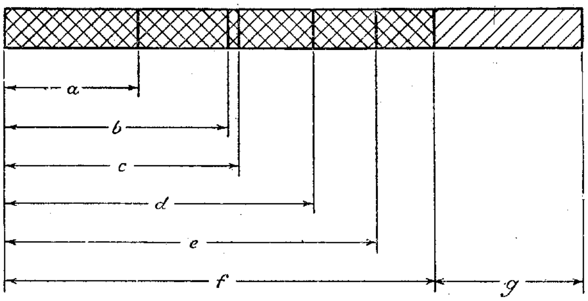


Fig. 8—Constitution of the Prefix Signal.

a = minimum splitting time
b = maximum splitting time
c = minimum prefix response time
d = maximum prefix response time
e = minimum transmitted time of prefix
f = maximum transmitted time of prefix
g = suffix

The duration of the transmitted signals can be accurately controlled. Their timing for purpose of recognition at switching points is not so easy. A pulse-control system is difficult, as the moment of commencement of the signal is indeterminate. Instant resetting is also necessary. Timing is therefore usually determined by means of a slow-to-release relay, and times of the order of 350 millisec. are the longest that can be measured reliably in this way.

It has been emphasized that the primary object of the prefix part of a signal is to divide a built-up connection into separate sections without causing any other change to the circuit. A subsidiary function may be allotted to it. It may be made to prepare the v.f. receiver and associated apparatus for the performance of a switching operation when the subsequent, or "suffix," part of the signal is received. As this will be transmitted after the receiver has been freed from external interference, a short pulse may be used.

(3.5) SIGNALLING CODE

(3.5.1) *General*

A system providing all the facilities usually required could be designed making use of either 600- or 750-c./s. currents only. Elaborate coding to distinguish signals by the number and duration of pulses would be necessary. Utilization of two frequencies provides a second set of distinctive "simple" signals and simplifies the code very considerably, but the signals which are then possible are more liable to signal imitation. There also arises the possibility of introducing "compound" signals to provide a third distinctive set of signal components. It has been found that, when signalling codes comprise both "simple" and "compound" signal components, the available codes are sufficient to enable the latter to be reserved solely for use as the prefix part of signals.

The facilities given by the voice-frequency system now in operation over many long-distance routes in Great Britain are provided by the use of simple signals.[6, 8] The decision not to make use of compound signals was taken at a time when it appeared that there were outstanding difficulties peculiar to the design of a v.f. receiver that would accept these as well as simple signals. These difficulties have largely disappeared as one result of five years' development, so that, although field experience with v.f. receivers which will accept simple and compound signals is small compared with that concerning earlier types, it now seems that such receivers can be made without greatly adding to the complexity of design and without increasing the difficulties of adjustment and maintenance. A code including both compound and simple signal components has since been brought into use in several countries.

It has already been shown that after conversation has commenced it is desirable to prefix that part of any signal designed to bring about a circuit change by another part, the primary function of which is that of splitting the built-up connection at points corresponding to boundaries of different signalling systems. As this common prefix will be the signal component most often occurring during conversation, assignment to it of a frequency, or frequencies, giving the best immunity from false splitting is a proper starting point for the construction of a code of signals.

Signals may consist of a single pulse or of a coded combination of two, or more, pulses. In the latter case the first pulse may constitute the prefix component. On account of the possibility of the required signal transmission path being barred by echo-suppressors or the v.f. receiver being made inoperative by speech or noise, single-pulse signals are chosen for periods when it is known that there will be no speech present, e.g., before dialling commences, or for the transmission of the dial impulses themselves. The latter are subject to interference by busy tone, but only when additional impulses cannot assist to make the connection.

(3.5.2) *Field Tests to Determine the Relative Liability of "Simple" and "Compound" Frequency Components to Signal Imitation*

Prima facie it would appear to be indisputable that a v.f. receiver needing the simultaneous response of two frequency-selecting elements before recording a signal would be more immune from speech interference than one needing the response of one frequency-selecting element only. In practice, however, other factors associated with receiver design enter to prevent the ideal response.

In view of the importance of the matter an extensive series of tests, to check the theoretical conclusion, was carried out in 1938 jointly by the Post Office and three British manufacturers of telephone equipment. The v.f. receivers used were built to a common specification which ensured that, as far as possible, immunity from false operation by speech was not secured at the expense of performance in other directions. These receivers were connected in parallel for some weeks to an inland long-distance circuit in commercial service, the method of connection being such that the speech voltage applied to their terminals could be raised or lowered at will from that normally existing. Later the test was continued using circuits from London to Berlin, Paris and New York, so that the effects of foreign language were also explored. Timing circuits gave a count of the operations of each receiver by speech for periods adjusted to suit line-splitting times of 50, 100, 150, 200, 250 and 300 millisec.

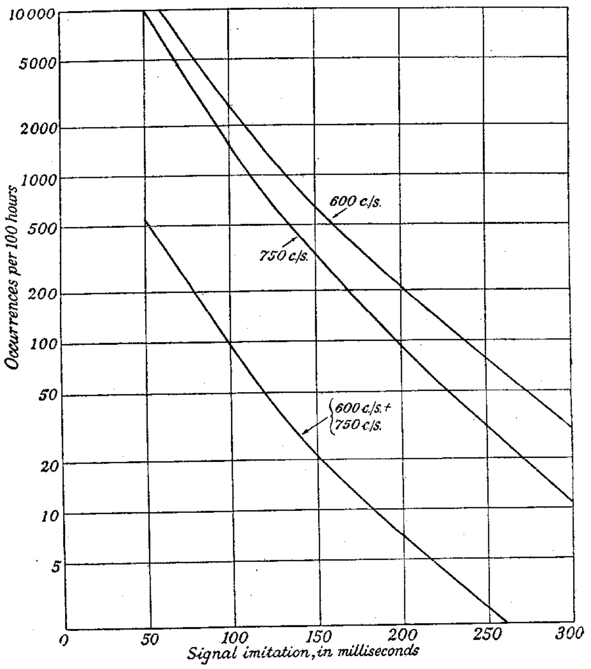


Fig. 9—Speech Immunity Tests of Representative V.F. Receivers Connected to an Inland Trunk Circuit at a Zero Level Point.

It was found that v.f. receiver operations resulting from speech varied in duration, those of short duration occurring much more frequently than those of long duration. From this it follows that a substantial degree of immunity can be obtained by using a time delay which masks false operations of comparatively short duration. It was next confirmed that, with equal time delays, false indications corresponding to the reception of compound-frequency signal components occurred less frequently than those corresponding to the reception of simple-frequency components. Alternatively, simple- and compound-frequency types of v.f. receiver could be made equally immune from speech operation by appropriate adjustment of the time delays. It was found that simple- and compound-signal components were approximately equal on account of signal imitation with v.f. receiver delays of 260 and 90 millisec. respectively. These delays necessitate minimum effective receive times of 400 millisec. for simple-frequency signals and 150 millisec. for compound-frequency signals. Results typical of those on which these conclusions are based are given in Fig. 9, where observations on a number of different receivers have been grouped according to the response concerned.

The results were affected to a certain extent by the level of the speech voltage, and quite wide variations were observed within small groups of v.f. receivers of the same design and adjusted to the same specification. Even wider variations are probable between factory-produced receivers, but the times just quoted should provide adequate margin against frequent false splitting.

(3.5.3) *Typical Signal Codes*

The results of the tests just described confirmed the advantages of a compound-frequency prefix signal, and later in 1938 the proposed standardization of such a signal for use on international circuits was supported by British repre-

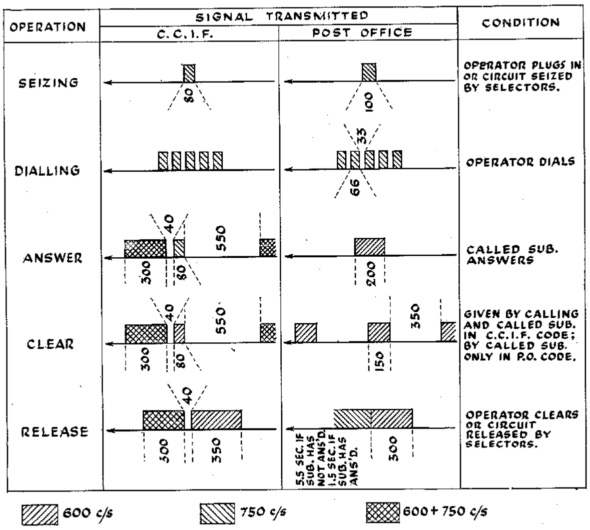

OPERATION
SIGNAL TRANSMITTED
C.C.I.F.
POST OFFICE
CONDITION
SEIZING
80
100
OPERATOR PLUGS IN OR CIRCUIT SEIZED BY SELECTORS.
DIALLING
33
66
OPERATOR DIALS
ANSWER
40
550
300
80
200
CALLED SUB. ANSWERS
CLEAR
40
550
300
80
350
150
GIVEN BY CALLING AND CALLED SUB. IN C.C.I.F. CODE; BY CALLED SUB. ONLY IN P.O. CODE.
RELEASE
40
300
350
5.5 SEC. IF SUB. HAS NOT ANS'D. 1.5 SEC. IF SUB. HAS ANS'D.
300
OPERATOR CLEARS OR CIRCUIT RELEASED BY SELECTORS.
600 c/s
750 c/s
600+750 c/s

Fig. 10—International and British Signal Codes. (Codes suitable for systems in which the call is controlled by an operator at the outgoing end.) Figures denote mean durations in milliseconds.

sentatives at a meeting of the C.C.I.F. Use of the compound frequency for other signals is disadvantageous, as the receiver response time is longer. This does not matter with the prefix signal. Most signal codes are therefore based on the use of simple-frequency signals for all signal components other than the prefix. Fig. 10 shows the signals proposed for use on international circuits to give the five essential facilities. The Table also shows how the same facilities are obtained within the British Post Office system by the use of simple-frequency signals only.

(4) *The Recommendations Made by the C.C.I.F. on the Subject of Voice-Frequency Systems*

(4.1) INTRODUCTION

In 1936 the International Consultative Committee on Long-Distance Telephony (C.C.I.F.), representing the major European Administrations and the U.S.A., adopted 600 and 750 c./s. as the frequencies to be reserved for signalling and dialling over international lines. This allocation was made at a time when it appeared that there was insufficient space in the audio range for the various services which were in course of development, and the desirability of earmarking certain bands for particular use was recognized. It was not generally appreciated that international connections would be specially prone to interference due to signal imitation, and in consequence frequencies other than those recommended have been used for national signalling and dialling systems.

To protect the international lines, the C.C.I.F. have recommended a limitation to the duration of pulses of the signalling frequencies which may pass out of the national systems. This recommendation will protect national systems using the recommended frequencies automatically. Use of other frequencies involves the necessity of providing special precautions to avoid interfering currents entering the national system.

The following recommendations were issued after a meeting of the C.C.I.F. held in Oslo in 1938.[12] A further meeting of the Committee investigating signalling and dialling was planned to be held in Paris during September 1939. Various documents representing the opinions of Administrations were circulated in preparation for the discussions. These documents support the recommendations made at Oslo.

(4.2) PREVENTION OF INTERFERENCE ON INTERNATIONAL CIRCUITS

To avoid interference on international circuits, it is recommended that at the end of impulsing a prefix signal, capable of splitting a connection after a certain time, should be transmitted before each signal.

The prefix should be as short as possible, difficult to produce by the human voice, and not liable to result in an incorrect signal if it is abbreviated or interrupted. The purpose of the prefix signal is to divide the connection into separate sections without causing any other operation. It is only the suffix, transmitted after the prefix, which causes other changes to the condition of the circuits. It is obvious that interference can result if the frequency, or the combination of frequencies, used for the prefix signal is connected to an international circuit.

It is probable that the use of a prefix composed of a mixture of the two frequencies (600 and 750 c./s.) will provide the greatest protection against operation by interfering currents. However, the use of this type of signal may introduce additional complexity into the v.f. receiver, so that, before making a definite choice, administrations are recommended to study and make tests to enable them to obtain more experience of systems utilizing both compound signals and simple signals.

Signals

It is recommended that the fundamental signals should be separated from the auxiliary signals. The following are the fundamental and auxiliary signals:

Fundamental Signals

(1) Seizing signal.
(2) Dialled impulses.
(3) Answer signal.
(4) Clear-back signal.
(5) Release signal.

Auxiliary Signals. (The following were listed as examples of what might be required.)

(1) Forward transfer signal.
(2) Offering signal.
(3) Breakdown signal.
(4) Ring forward signal.

Constitution of the Signals

(1) Seizing signal—a single short impulse of 750 c./s.
(2) Dialled impulses—impulses of 750 c./s.
(3) Answer signal—prefix followed by a short signal of 750 c./s. (see remark under "Release Signal").
(4) Clear-back signal—prefix and suffix of 600 c./s. This signal is repeated complete. The interval between signals should be greater than 550 millisec. The signal continues until release, or until the called party returns to the line.
(5) Release signal. There are two cases to consider:
    (*a*) In certain cases the release signal is sent forward from the caller to the called. It is made up of the prefix followed by a long suffix of 600 c./s.
    (*b*) In other cases, a forward signal comprising a prefix followed by a short suffix of 600 c./s. This signal results in the transmission of a release signal which is sent in the backward direction. The release signal is made up of a prefix followed by a long suffix of 600 c./s.

(It was here noted as important that arrangements should be made to ensure that these signals are received with certainty. The Directive with regard to Auxiliary Signals was to have been issued later.)

Signal Length

(1) Short signal: 60–100 millisec.
(2) Long signal: 300–400 millisec.
(3) Compound-frequency prefix: 250–350 millisec.
(4) Simple-frequency prefix: to be fixed later.
(5) Pause between prefix and suffix: 30–50 millisec.
(6) Repeated signals: the pause between two consecutive signals should be equal to, or greater than, 550 millisec.

(4.3) Receiver Specification

Limits for Signal Frequencies

The admissible variation in frequency for the generation of signals on international circuits should be ±0.5 per cent. The receiver should function with a relatively uniform response over a band of ±22.5 c./s. from the nominal frequency in order to provide for variations at the source and change of frequency due to carrier shift.

Limits for the Power which may be used

(1) *Simple frequency*
    2 mW, with a variation of ±1 db., measured at the point of zero relative level and measured as a steady frequency.
(2) *Compound frequencies*
    1 mW of each frequency, measured at the point of zero relative level, with a termination of 600 ohms, and measured as a steady frequency with a variation of ±1 db., provided that the voltage of the two frequencies does not differ by more than 0.5 db.

Dialled Impulses

It is desirable to standardize the impulsing speed for international circuits. 10±1 i.p.s. is recommended. It is also recommended that the impulse ratio should be standardized on international circuits, but actually it is not possible to fix this ratio.

Insertion Loss

The insertion loss of the voice-frequency receiver should not exceed 0.3 db. for any frequency transmitted by the circuit.

Receiver Operating Limits

The receiver should be designed for connection to a point of nominal relative level of from 0 to −10 db. and should operate correctly when the actual relative level differs from the nominal relative level by ±5 db.

General

In order to prevent a voice-frequency signalling circuit from being indicated free at an outgoing end before the circuit is free at the distant end, the principle of release should maintain the circuit indicated busy at all points of access until it is actually available at all points.

(4.4) PREVENTION OF INTERFERENCE ON NATIONAL CIRCUITS

It is, in fact, difficult to specify general precautions capable of avoiding interference in national systems which use frequencies other than 600 or 750 c./s. when these systems are connected to an international circuit. The following precautions can, however, avoid interference to national systems utilizing 600 and 750 c./s., chosen by the C.C.I.F., and connected together by international circuits. It is recommended that means should be provided to prevent a voice-frequency current passing from the national to the international circuit if its length exceeds:

400 millisec. for a simple frequency (600 or 750 c./s.), or
150 millisec. for a compound frequency (600 and 750 c./s.).

(5) *A Forecast of the Future Development of Signalling and Dialling Over Long-Distance Telephone Circuits*

(5.1) INTRODUCTION

Before future developments can be forecast, consideration must be given to the requirements which are likely to be made with regard to long-distance signalling and dialling, particularly as a result of more extensive replacement of operators by automatic switching equipment in the setting up of calls. Consideration must equally be given to the type of transmission system that is likely to be used, for it is probable that this may influence directly the form which the signalling system should take.

(5.2) PROBABLE DEVELOPMENTS IN SIGNALLING

One probability is the enlargement of the area over which the subscriber is permitted to make connection without the assistance of an operator. Widespread introduction of subscriber dialling must inevitably be delayed for a number of years. It is likely to be preceded by a period of more limited mechanization during which the densely populated areas become accessible for subscriber dialling from towns at distances up to 100 miles or so. Such calls could be identified by a special 2-digit prefix and would not necessitate the subscriber dialling a total of more than 10 digits.

As the distance extends over which subscriber dialling is permitted, problems concerned with routing the call become more difficult. At present there are operating in this country a large number of multi-exchange areas each using a separate numbering scheme. Group centres and zone centres are arranged to suit the needs of general administration and the existing line plant. A national switching plan must be prepared to enable the various stages of mechanization to be introduced from time to time.

To assist the subscriber and the P.B.X. operator, it will be necessary for the overall switching plan to be based on a national numbering scheme. It is also very desirable that the maximum number of digits for any one subscriber to reach any other should not be large. One step towards achieving this object might be a reduction in the number of zone centres so that a single "zone" digit following the general long-distance prefix may identify the zone required. For example, the country might be divided into zones based on the following switching centres:

(1) London.
(2) Bristol.
(3) Birmingham.
(4) Manchester.
(5) Leeds.
(6) Newcastle.
(7) Edinburgh.
(8) Glasgow.
(9) Belfast.

The tenth digit might be used to obtain access to an operator for international calls.

To extend the connection from the zone centre to any dependent area, it would be necessary to allocate a series of "area" codes which might be restricted to 3 digits as a maximum. The 1,000 combinations so formed would be usually sufficient for each zone, and some of the larger areas with 5- or 6-digit exchange numbers could be allotted 2-digit codes.

In some Continental countries the digit 0 is used as a general long-distance prefix, but in this country there are objections to this arrangement because this digit is well established for providing access to an operator. A 2-digit prefix would be necessary and the numbering plan would then be constituted as follows: 2 digits for long-distance prefix, 1 digit for zone prefix, 3 digits for area prefix and 4 digits for exchange number, giving a total of 10 digits.

Economical provision of line plant requires flexibility in the use of circuits which may be employed to build up long and complicated connections. This will probably lead to the introduction of storage on some calls. The storage period would be utilized, when necessary, for the translation of one or more of the digits dialled by the subscriber into such others as the circumstances required. Storage would be accompanied by regeneration of all impulse trains but, unless storage and regeneration were introduced on all calls, development of the long-distance signalling system would not be greatly influenced.

Prior to the introduction of subscriber dialling, either in part or on a full national basis, it is believed that an intermediate stage of development with an extensive use of cordless switchboards should be expected. Many of the selectors which are provided for the use of cordless switchboards can be utilized without rearrangement for subscriber dialling as mechanization proceeds. These switchboards are more flexible in arrangement and simpler in operation than the multiple type. To compensate for loss of direct access to the long-distance line, facilities will be necessary to indicate to the operators when a circuit in any particular direction becomes available. The indication will enable the available lines to be loaded to the maximum efficiency during conditions of congestion. Thus the succession of events will be a progressive reduction in the number of operators required for each call, tending to the condition when the subscriber is capable of setting up all long-distance connections. Operators must be retained for international calls, for such special services as personal calls, and for assisting subscribers unable to complete their own connections, more especially during periods of congestion.

For large cities and for groups of towns, it seems probable that in place of a centralized long-distance switchboard on which terminate a large number of lines, some decentralized system utilizing a ring main will be adopted (see Fig. 11). With this layout the long-distance lines will terminate at the periphery of the area.

Repeated operation of the subscriber's message register, known as multi-metering, is now used in this country as a means of recording calls up to the value of 4d., corresponding approximately to a 15-mile connection, but it is unsuitable for the more expensive calls, as details are not recorded. Before the subscriber can be allowed to set up expensive calls without the intervention of an operator, automatic equipment might be required to give a printed record of the call and to enable the necessary particulars to be entered on the account as at present. Such equipment has already been installed in Belgium. An example of

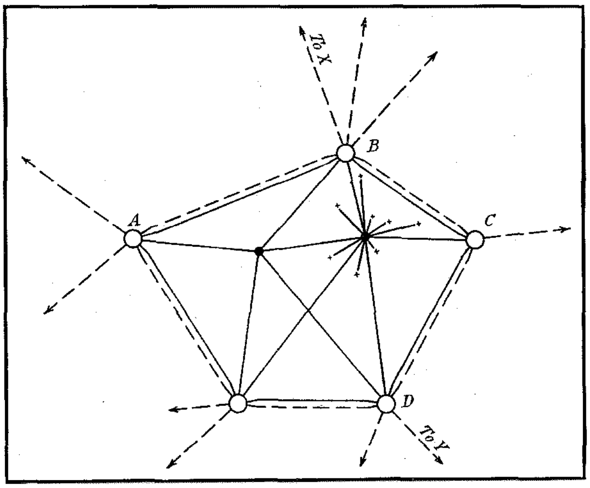


Fig. 11—Decentralization of Long-Distance Switching. (Two only of a number of likely control centres have been shown, and only the local exchanges connected to one of the control centres.)

○ *Ring main switching centres*
● *Control switching centres*
+ *Local exchanges*
——— *Audio-frequency cables*
– – – *Multi-channel carrier cables*

(*Note: A call from X to Y would be switched round the ring via B, C and D.*)

GLA 3376 C 6 1.15 PM 27.6 LEEDS 53321 5/10

Fig. 12—Typical Long-Distance Ticket

This ticket conveys the following information. Subscriber number GLAdstone 3376 has called LEEDS 53321 at 1.15 p.m. on the 27th June. The call was set up on circuit number 3(C), the duration of the call was 6 minutes and the charge is 5s. 10d. The latter half of the ticket represents the information necessary for the subscriber's account.

a ticket from a machine developed for use in step-by-step areas is shown in Fig. 12.[15]

It has been argued that on calls for which the tariff is more than a few pence the subscriber is entitled to the assistance of an operator to check that the speech level is satisfactory and to render any service which is possible. On the other hand the ability to make a long-distance connection without the intervention of any operator would be of importance to many subscribers who would possibly not appreciate the improvements in service resulting from the use of automatic signalling and dialling by an operator. Whatever the limit to which subscriber dialling is eventually permitted, it is certain that an operator will be available to render assistance if required. Subscriber-to-subscriber dialling over large areas is practiced in many Continental countries, notably Germany, Switzerland, the Netherlands and Belgium.[10, 11, 16] Before the commencement of the present war it was intended to provide subscriber-to-subscriber dialling over the whole national network in all these countries, and considerable development had taken place.

The switching requirements which are likely to influence the development of future long-distance signalling systems cannot be enumerated with any degree of certainty, but at the present time it is to be expected that the following factors will be of importance:

(i) The connection will be under the entire control of the subscriber.

(ii) Subscribers must be able to obtain access to an operator for special services and in case of difficulty with the long-distance circuits.

(iii) Speedier switching and release of built-up connections will result in more switching points and shorter lines.

(iv) Alternative routes will be established automatically when needed. Introduction of the additional switching digits may require storage on some calls but not necessarily on all.

(v) The subscriber will be protected from complicated dialling codes by a comprehensive national dialling scheme. Such a scheme and the probability of more switching centres may involve storage and translation on some calls.

(vi) The answer signal must be safeguarded from subscriber interference.

(vii) The ability to use either of two seizing signals, depending on the ultimate destination of the call.

(5.3) THE NATURE OF FUTURE TRANSMISSION SYSTEMS

In April 1937, Col. A. S. Angwin and Mr. R. A. Mack[9] gave The Institution an account of the carrier telephone system then operating between Bristol and Plymouth and affording 12 telephone channels per pair of wires in the frequency range 12–60 kc./s. "Go" and "return" channels were supplied by separate cables. The success of this installation was such that 12-circuit carrier systems were adopted by the Post Office as the premier means of providing additional groups of long-distance circuits. A network of cables was planned interconnecting many of the more important centres in the country. Provision of this network had progressed to a considerable extent before September 1939, and 12-circuit systems have since been brought into commercial service on other routes.

There was described in the same paper a parallel line of development[4] exemplified by the provision of the first British coaxial cable. This was laid between London and Birmingham and was designed to give 320 carrier telephone circuits within the frequency band 0.5–2.1 Mc./s. The cable was equipped with wide-band amplifiers at intervals of approximately 7 miles, and separate coaxial tubes were used for the two directions of transmission. In anticipation of a continued and increasing growth in the trunk traffic, the original London–Birmingham cable was extended to Manchester, Leeds, and Newcastle. It now appears definite that the economies inherent in a wide-band transmission system are such that, even allowing for the considerable cost of the associated terminating equipment, these systems will form a future means of providing large groups of long-distance circuits in this country. Where a large group of circuits is required between switching centres upon long-distance routes the wide-band system may prove economical for distances down to 50 miles due to the saving resulting from the common use of plant and equipment.

It is difficult to forecast the post-war demands for additional long-distance circuits, but in the years immediately preceding 1939 long-distance traffic was increasing in Great Britain at the approximate rate of 25% per annum. Without very great capital expenditure it would have been impossible to provide the additional circuits required, solely by extension of the existing network of audio-frequency cables. 12-circuit carrier and wide-band coaxial systems give means of providing these circuits much more cheaply. It appears, therefore, that the long-distance transmission system of the future will consist of wide-band coaxial systems connecting main centres, with 12-circuit carrier systems as a subsidiary. 12-circuit carrier and wide-band coaxial systems have features in common. The latter are built up from groups of 12 speech channels, and each group, apart from its location in the frequency spectrum, is similar to the group transmitted, in the case of the 12-circuit system, within the frequency range 12–60 kc./s. Adjacent speech channels are spaced at 4-kc./s. intervals. Short links between zone and group centres may be 12-circuit carrier or 4-wire audio circuits. The latter type of circuit will probably not be used except between centres which are sufficiently close together to permit the operation of d.c. dialling systems.

An attempt has been made in Fig. 13 to indicate the probable nature of the links included in a built-up connection of the immediate future.

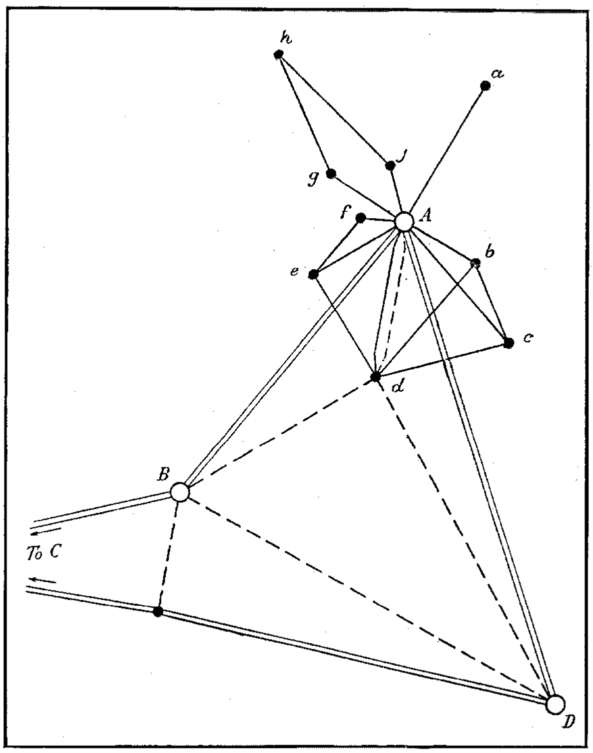


Fig. 13—Schematic Layout of Modern Long-Distance Telephone System. (A few only of the lines have been indicated and the group centres in Zone A only. Telephone exchanges are connected to the group centres and have not been shown.)

A Primary switching centres (zone centres)
○
a Secondary switching centres (group centres)
●

═══ *Coaxial systems*
– – – – *12-circuit systems*
——— *Audio systems*

(5.4) Possible Development of 2-Voice-Frequency Signalling

Any picture of the future long-distance telephone service should include the provision of automatic signalling and dialling by continued use of voice-frequency systems with possible improvements or modifications. Alternatively, entirely new signalling systems may be introduced for operation over the special types of speech transmission path likely to be employed in the future. Initial consideration must be given to the first of these possibilities.

The power-handling capacity of the amplifiers included in a wide-band coaxial system is decided by the average speech level of the telephone channels. Peak levels may be very much higher, but do not occur simultaneously on all channels. At present voice-frequency signals are sent at levels higher than normal speech and the possibility of some reduction being necessary must be kept in mind.

Whatever the future means of providing connections between switching centres more than a few miles apart, the circuits will almost certainly be of the 4-wire type, comprising separate "go" and "return" paths. These paths may consist of separate pairs in an audio-frequency cable or of separate channels in a multi-circuit carrier or wide-band coaxial system. It has already been shown that echo-suppressors connected to 4-wire circuits constitute one of the major obstacles to the transmission of voice-frequency signals. Although on future high-velocity circuits echo effects will not be troublesome, the retention of echo-suppressors to limit singing currents is possible on some circuits to ensure stability. Such echo-suppressors will normally be connected at switching centres, as with carrier circuits intermediate positions are unsuitable.

Difficulties due to interference by signals enumerated in Section (3.4.1) can be avoided if the voice-frequency signalling equipment is connected to the 4-wire portion of the long-distance line, because in this position the circuit is divided into separate "go" and "return" transmission paths. Such an arrangement eliminates unwanted operation of the v.f. receiver from currents passing in the opposite direction and also provides a means for avoiding the interference due to the terminal echo-suppressors. There is, however, a serious disadvantage in connecting the voice-frequency signalling equipment on the 4-wire side, because it increases the difficulty of passing the received signals to and from the switching equipment. These operations need to be controlled in the d.c. portion of the circuit on the exchange side of the terminating set. Additional conductors may be necessary between different buildings if transmission and switching equipments are located separately.

With manual operation all long-distance circuits have been provided with a 2-wire termination and appear on the switchboard in the same way as junction and local circuits. Although technical difficulties exist with the switching equipment if circuits are connected together 4-wire to 4-wire, it is certain that the possibilities of this method will be studied where long-distance lines are joined in tandem,[13] because with 4-wire switching the number of paths included in the built-up connection and around which singing currents can circulate is reduced. The complication with 4-wire switching does not lie with the transit connection but, more particularly, on those calls which need to be switched to a local line operating on a 2-wire basis. The way in which the connection is to be extended will probably remain unindicated until one or more selecting digits have been received, and this uncertainty may necessitate the transmission, later, of a special signal in a backward direction. This signal may be valuable for other functions, such as inserting an echo-suppressor. The arrangement places the v.f. receiver in the 4-wire side but leaves the position of the terminating set unspecified, and some interesting possibilities arise.

It has been noted that storage and regeneration of dialled impulses at certain switching centres is likely in the future. The introduction of storage will facilitate automatic adjustment to be made of the overall gain on a built-up connection. Without storage, the short inter-train pause between successively dialled digits does not provide the opportunity for the transmission of a signal long enough to determine the automatic setting of the gain of a repeater. Regulation of the overall gain of a circuit may become a greater problem in the future as both the total attenuation and the total gain increase. These two factors are considerable in modern circuits. On a 300-mile connection over coaxial cable (London-Newcastle, for example) the total attenuation is of the order of 2,000 db., i.e., if it were not for the compensating gain introduced by amplifiers at regular intervals along the route the received speech voltage would be reduced to $1/10^{100}$ of that transmitted. It is difficult to give any illustration of this ratio. Comparison of the total power radiated by the sun with the light emitted by a glow-worm is roughly equivalent to the attenuation of the coaxial line between London and Birmingham. Because of the great attenuation and gains involved, automatic regulation appears to be extremely desirable. Hitherto individual links have been set to have approximately zero attenuation, but many difficulties would be avoided could the normal attenuation of each link be increased slightly and the net attenuation of a built-up connection controlled by automatic adjustment of the gain of repeaters at switching points. The signalling frequencies transmitted with 2-voice-frequency systems provide a basis for the automatic setting of the gain of a circuit. It should be noted, however, that the ability to do this is also inherent in other long-distance signalling systems.

(5.5) SIGNALLING AND DIALLING SYSTEMS DESIGNED ESPECIALLY FOR OPERATION OVER MULTI-CIRCUIT CARRIER SYSTEMS

Use of multi-circuit carrier systems, whether of the 12-circuit or wide-band coaxial types, in increasing quantities justifies consideration of the special problem of providing automatic signalling facilities over such systems by the most economical means possible.

Signalling channels operating in a frequency band entirely separate from the speech frequency band have been used to provide automatic facilities on open-wire carrier systems of certain types.[19] Such systems are simple, but the frequency band required might not always be available in multi-circuit and wide-band systems.

The carrier frequency itself has been used for signalling purposes on certain systems in which the signalling forms an integral part of the transmission equipment. This method of signalling increases the difficulties of filter design, and difficulties may be experienced with the precautions which have to be taken to keep the leakage of current at the carrier frequency small. Even so, a fairly high signalling power may be necessary.

(5.5.1) *Signalling Facilities Provided Separate from the Speech Channels*

Suggestions have been made that signalling channels suitable for use with multi-circuit carrier telephone systems could be provided by means

TABLE III

COMPARISON OF VARIOUS LONG-DISTANCE SIGNALLING SYSTEMS

Location of signalling channels 1	Means of signalling 2	Method of avoiding speech imitation of signals 3	Usual or suggested field of application 4	Facilities provided		Transmission of signals at transit switching centres 7
				Signalling 5	Dialling 6	
(1) Within the speech channel						
(1*a*)	500/20, i.e. 500 c./s. modulated at 20 c./s.	By time delay and combination of 2 frequencies	Technically possible on all types of circuit, infrequently installed on short lines on account of cost	Only ringing signals for calling operator	No	Manual repetition necessary
(1*b*)	2 voice-frequencies, usually 600 and 750 c./s.	By time delay and guard circuits	As (1*a*)	Sufficient distinctive signals for full automatic supervision provided by coded pulses	Yes	End-to-end signalling possible, failing which precautions to avoid interference between different sections must be taken
(2) Adjacent to the speech channel						
(2*a*) Sub-audio						
(2*a*)i	16⅔ c./s.	Signalling frequency is below effective speech band	Limited to audio-frequency circuits	Only ringing signals for calling operator	No	Manual repetition necessary
(2*a*)ii	50 c./s.	As (2*a*)i	As (2*a*)i	Full automatic supervision provided by distinguishing pulse signals on a time and sequence basis	Yes	Conversion into d.c. signals and repetition necessary
(2*b*) Super-audio	2,500 c./s. or higher frequency	By low- and high-pass filters to separate speech and signal channels	Open-wire carrier circuits	As (2*a*)ii	Yes	As (2*a*)ii
(3) Carrier, appropriate to the speech channel	Channel carrier frequency	By band-pass filters; additional modulation process sometimes necessary	Carrier systems, in which it forms an integral part of transmission system	As (2*a*)ii	Yes	As (2*a*)ii
(4) Segregated from the speech channel						
(4*a*) Within carrier group	Specific frequencies transmitted over one of a group of carrier circuits, the selected circuit being subdivided as in v.f. telegraph systems	Signalling currents use separate channel	12-circuit carrier and wide-band coaxial systems only	Full automatic supervision provided by continuous signals, or, failing this, by pulses as with (2*a*)ii	Yes	As (2*a*)ii
(4*b*) Outside carrier group	Specific frequencies transmitted over a frequency band, provided outside the carrier group, the selected frequency band being subdivided as in (4*a*)	Signalling currents use separate channel usually in the band below 12 kc./s.	12-circuit carrier systems only	Full automatic supervision provided by continuous signals as with direct current	Yes	As (2*a*)ii

similar to those employed in voice-frequency telegraphy. The proposed schemes envisage the allocation of one speech channel from a group to provide signalling facilities for the remainder of the group, the allocated speech channel being sub-divided by filters to give the appropriate number of signalling channels in the same way as a 12- or 18-channel voice-frequency telegraph system is obtained by sub-division of a speech channel into bands, each having a width of 120 c./s. In order that the complete system should be flexible, it is not desirable that the signalling channels appropriate to more than one, or at the most two, groups of 12 speech channels should be associated. A convenient scheme would be for one speech channel in each 12-channel group to be allocated for signalling and to be sub-divided so that it provides signalling facilities for the other 11. Alternatively, the selected speech channel could be sub-divided to provide many more signalling channels, but with such sub-division, or with cheapened filters, the frequency band-width

TABLE III (*Continued*)

COMPARISON OF VARIOUS LONG-DISTANCE SIGNALLING SYSTEMS

Modifications required to transmission system	Remarks concerning nature of signal receiver	Comparative space occupied by signalling equipment	Comparative first cost of signalling equipment	Extent of practical experience	General remarks
8	9	10	11	12	13
None	Comparatively complex and requires specialized maintenance	0.5	0.5	Large	Signal imitation gives rise to the risk of occasional short-period interruptions
None	Similar to (1*a*) but more elaborate; requires specialized maintenance	1.0	1.0	Fair	As (1*a*)
Bypass signal path, or signal-repeating apparatus at each repeater station	Simple and robust	0.1	<0.1	Large	To the cost of the terminal equipment (Col. 11) must be added that of the units necessary at repeater stations to bypass or repeat the signals
As (2*a*)i	As (2*a*)i	0.5	0.4	Fair	To the cost of the terminal equipment (Col. 11) must be added that of the modifications or additional equipment necessary at each repeater station (Col. 8)
Filters are necessary to separate speech and signal channels, and some speech impairment results	Comparable with (1*b*)	1.5	1.5	Small	A speech transmission system with this method of signalling will not usually meet C.C.I.F. requirements
Design of speech and signalling terminals completely interdependent. Provision of signalling makes channel filter requirements more difficult to meet and additional filters are necessary to separate speech and signal currents	Built into carrier system and requires specialized maintenance	1.0	1.5	Small	
A proportion of the speech circuits must be abandoned to nonrevenue-earning purposes	Follows orthodox v.f. telegraph apparatus design and requires corresponding maintenance	Not developed	1.5 to 2	None	To the cost of the terminal equipment must be added that due to the loss of a proportion of circuits to revenue-earning purposes. It may be economical to make use of a dialling path having a greater band width than the signalling path (e.g. the speech channel itself) in order to cheapen the design of the filters separating signalling paths or to make a greater number of signalling paths available within a given frequency band
Restricts the use of the frequency band below 12 kc./s. for such purposes as music transmission	As (4*a*)	Not developed	1.5 to 2	None	As (4*a*) except that signalling frequency band may not be otherwise revenue-earning

included in each channel would be insufficient for the transmission of dialling impulses without the introduction of distortion exceeding permissible limits. Dialling impulses could, however, be transmitted either over the speech circuit, which is not required for conversation during dialling, or over separate dialling channels which are connected to the circuit only when required. The band-width required for each individual channel to provide signalling facilities other than dialling could be reduced since considerable distortion can be permitted to these signals. Apart from the reduced flexibility of such a system, the reduction in cost of the individual signalling channels would probably more than compensate for the additional complication.

Independent channels are used for the two directions of transmission, and signalling can take place independently and, if necessary, simultaneously in both directions. Signalling is possible during the periods when speech is also being transmitted, and the signalling system is entirely free from interference due to speech currents. The facilities which the system is capable of providing approximate closely to those obtained by d.c. signals in local networks, but this is not necessarily true if the signals have to be transmitted over wide-band coaxial systems, which may in the future contain up to 1,000 channels. In such cases the overloading of intermediate amplifiers would result from the use of continuous signals at levels exceeding that of normal speech. Modification of d.c. signalling methods would therefore be necessary.

The cost of systems employing separate signalling channels has not yet been worked out in detail. It will possibly be more than that of 2-voice-frequency systems, apart from the fact that to it would have to be added the cost of the circuit allocated for signalling purposes and therefore lost for speech. There are apparent advantages of simplification and ease of maintenance, but complications may arise with respect to the transmission of signals over built-up connections. Conversion into d.c. signals will generally be necessary at transit switching centres, apart from the obvious necessity of such conversion at points where different types of transmission system meet. In this respect systems employing separate signalling channels compare unfavourably with voice-frequency signalling. In conditions of emergency necessitating a rapid rearrangement of the routing they also compare unfavourably with voice-frequency systems in which the speech path serves also as the signalling path.

(5.6) CONCLUSIONS AS TO FUTURE DEVELOPMENT

In Table III an attempt has been made to summarize the relative advantages and disadvantages of various possible methods of signalling over long-distance circuits. Methods which have been in widespread use for a number of years, but which give very restricted facilities, such as ringing only, have been included to form a basis of comparison in such matters as cost and complexity. Other methods, which give greater facilities, but which have not yet had the test of extensive practical use, have also been included.

Any review of the means by which long-distance signalling and dialling may be accomplished suggests that 2-voice-frequency systems have certain outstanding advantages as regards their capability of operation over any type of speech transmission path. They alone permit through signalling over a patchwork connection consisting of different types of transmission systems and allow end-to-end signalling when several trunk links are connected in tandem. In view, however, of the interference between different sections of a built-up connection, which is discussed in Section (3), the advantages of end-to-end signalling are problematical. The increasing proportion of long-distance circuits to be provided by means of 12-circuit carrier and wide-band coaxial systems merits, however, the consideration of other means of signalling specially adapted for such systems. Although limited in their application to carrier telephone systems, such means of signalling have the advantages of avoiding somewhat formidable difficulties due to speech interference.

(6) *Acknowledgments*

The authors wish to express their thanks to the Engineer-in-Chief of the Post Office and to Standard Telephones and Cables, Ltd., for permission to publish the information contained in this paper. They would also take the opportunity to thank many colleagues who have been associated with them in work that has been described, and especially Mr. T. H. Flowers and Mr. S. E.

Aldrick for assistance during the compilation of the paper.

(7) *Bibliography*

1. H. S. Osborne: "General Switching Plan for Telephone Toll Service," *Bell System Technical Journal*, 1930, **9**, p. 429; *Bell Monograph*, B.485.
2. T. Laurent: "The Swedish Voice-frequency Signalling System," *L. M. Ericsson Review*, 1931, Nos. 1–3, pp. 64–80.
3. E. Frey: "Automatic Long-distance Switching and National Dialling, Basle-Switzerland," *Electrical Communication*, 1934, **12**, p. 311.
4. L. Espenschied and M. E. Strieby: "Wide-band Transmission over Coaxial Lines," *ibid.*, 1934, **13**, p. 159.
5. T. S. Skillman: "Developments in Long-distance Telephone Switching," *Journal I.E.E.*, 1934, **75**, p. 545.
6. H. S. Smith, T. H. Flowers and B. M. Hadfield: "Signalling on Trunk Circuits," *Post Office Electrical Engineers' Journal*, 1936, **29**, p. 41.
7. W. Hatton: "Field Trial of 50-c./s. Signalling on Toll Lines," *Electrical Communication*, 1936, **15**, p. 107.
8. T. H. Flowers and B. M. Hadfield: "Voice-frequency Signalling on Trunk Circuits," I.P.O.E.E. Paper No. 162.
9. A. S. Angwin and R. A. Mack: "Modern Systems of Multi-Channel Telephony on Cables," *Journal I.E.E.*, 1937, **81**, p. 573.
10. J. A. Marchal and G. E. H. Monnig: "Recent Progress in Automatic Ticketing in Belgium," *Electrical Communication*, 1938, **17**, p. 72.
11. J. P. Verlooy and M. D. Hertog: "National Dialling in the Netherlands," *ibid.*, 1938, **17**, p. 78.
12 Comité Consultatif Internationale Téléphonique (C.C.I.F.), Livre Blanc, 1938, **1** (ter).
13. M. Langer: "Eine zweckmässige Zusammenschaltung der Fernleitungen in der Fernämtern," *Telegraphen-Fernsprech-Funk- und Fernsehtechnik*, 1938, **27**, p. 413.
14. W. H. B. Cooper: "A Differential Impulse System of Dialling over Long Junctions," *Post Office Electrical Engineers' Journal*, 1938, **31**, p. 108.
15. E. P. G. Wright: "The Application of Automatic Ticketing to Step-by-Step Systems," *Electrical Communication*, 1939, **17**, p. 230.
16. E. Frey: "Die Entwicklung der automatischen Telephonie im Weitverkehr der Schweig," *Technische Mitteilungen der schweizerischen Telegraphen und Telephon Verwaltung*, **17**, No. 2, p. 44.
17. C. McHenry: "The New Melbourne Trunk Exchange," *Telecommunication Journal of Australia*, 1940, **2**, p. 298.
18. E. P. G. Wright: "Development Aspects of International Voice-frequency Signalling and Dialling under consideration by C.C.I.F.," *Electrical Communication*, 1939, **18**, p. 3.
19. F. P. O'Grady: "Voice-frequency Dialling over Trunk Lines in S. Australia," *Telecommunication Journal of Australia*, 1940, **2**, p. 337.

Selenium Rectifiers and Their Design*

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Editor's Note

This is the third of a series of articles[1,2] *on Selenium Rectifiers recently published in this journal and is devoted to design methods. The present article parallels presentations before the American Institute of Electrical Engineers.*

The design procedures and computations described, as well as the nomenclature utilized, have proved useful in expediting the selection of Selenium Rectifier plates or discs and in consummating designs of complete rectifier units even in cases of complicated field requirements. Insofar as the author is aware, the procedures outlined have not heretofore been applied to the design of metallic plate rectifiers.

Selenium Plates

THE rectification of alternating currents by means of the Selenium Rectifier takes place wholly within the constituent plate or plates, seven sizes of which are shown in Fig. 1. The rectifying medium of this electronic device consists of selenium; the principle of operation is similar to that of other dry plate rectifiers, i.e., low resistance in the forward direction and high resistance in the reverse direction. A metal plate serves as back electrode; over it, a layer of selenium is deposited, thin enough to give minimum internal losses, but sufficiently thick to withstand high inverse voltage. A soft metal of low-melting temperature is then applied over the selenium layer to form a front electrode. Finally, by means of controlled processes, a barrier layer is formed between the selenium and the front electrode.

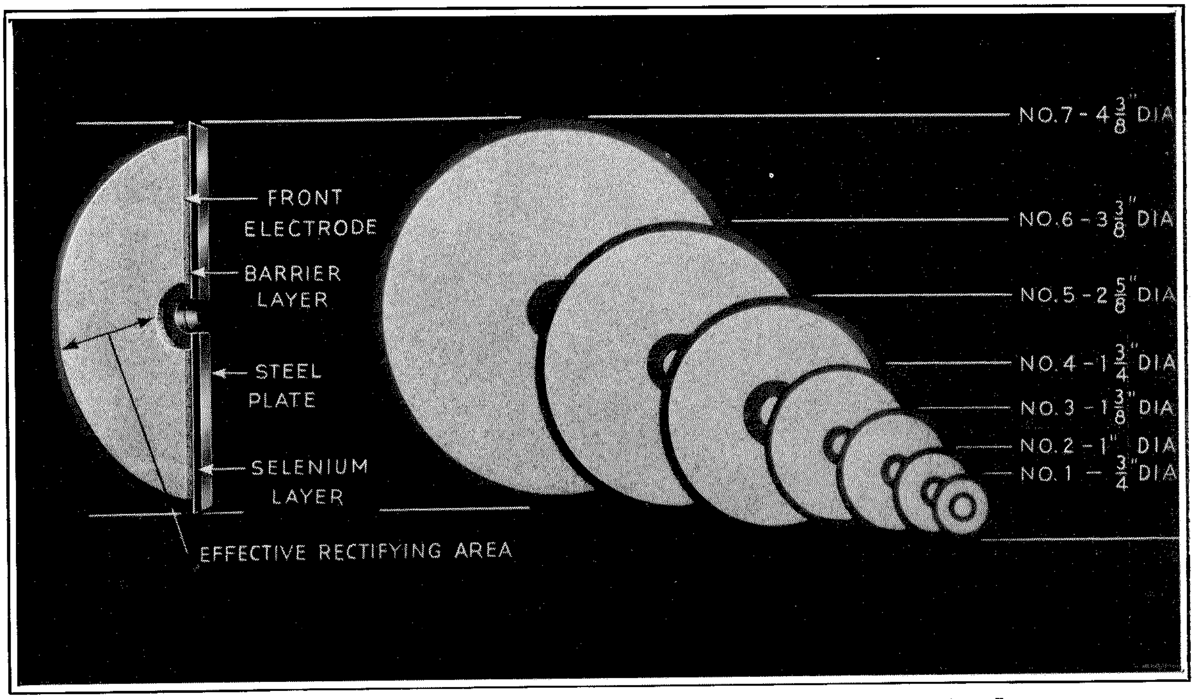

Fig. 1—Left: Cross-Section of a Selenium Rectifier Plate Showing the Sequence of Various Layers. Right: Seven Basic Sizes of Selenium Rectifier Plates.

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* Article is based on paper presented at meetings of the A.I.E.E.: Southwest District, St. Louis, Mo., October 10, 1941; Northeast District, Schenectady, N. Y., May 1, 1942. Published in *A.I.E.E. Transactions*, Vol. 61, 1942, July Section.

[1] For references see bibliography.

Selenium Rectifier Stacks

Rectifier stacks are produced by assembling Selenium Rectifier plates (40 plates are usually maximum) on a center stud with contact discs or washers interspersed between plates. Series and parallel arrangement can readily be provided as required by inserting insulators between plates and introducing terminal lugs into the stack.

A stack consisting of forty plates may be connected in several different ways; for example, as a bridge circuit unit having ten plates in a series and one plate in parallel (4–10–1), or one plate in series and ten in parallel (4–1–10). The same stack may also be connected as a half wave rectifier having all forty plates in series to take care of voltage and one plate in parallel to take care of current (1–40–1). Further, the forty-plate stack may also be assembled as a doubler (2–10–2), two of which make a bridge circuit rectifier with ten series and two parallel plates in each arm of the bridge.

For the three phase half wave circuit the total number of plates must be a multiple of three to allow a total connection such as 3–6–2 for a thirty-six plate single stack unit. Similarly, this latter stack, if connected as 6–6–1, becomes either a bridge or center tap three phase rectifier.

Rating of Plates

Current ratings of selenium plates are a function of their effective rectifying areas and heat-dissipating capacities. Table I lists seven basic plates, ranging from three-quarters of an inch to four and three-eighths inches in diameter; it also shows ratings of the basic plates in various rectifier circuits. The ampere capacities shown in this Table are based on an ambient temperature of 35° C., and were determined experimentally. The requirements of a Selenium Rectifier, in respect to current, are always met by selecting the proper size of plates and their number in parallel, if the total rating of the rectifier exceeds the rating of an individual plate.

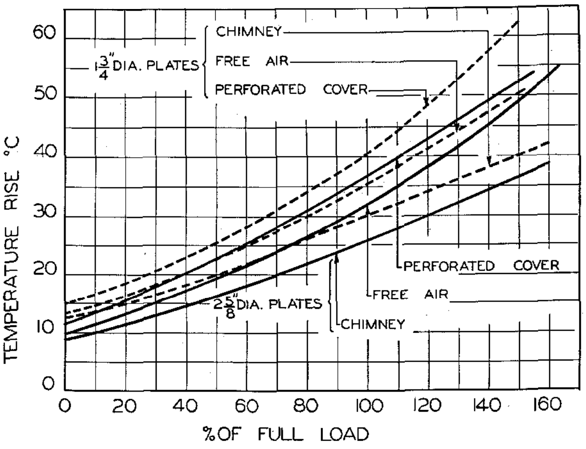


Fig. 2—Temperature Characteristics of Two Selenium Rectifiers Under Three Different Cooling Conditions: (1) in a cabinet with perforated top and bottom covers; (2) in free air; (3) in a chimney-like enclosure fully open at the top and bottom.

The ratings of the plates shown in Table I can be increased by providing additional cooling. Doubling the spacing between plates assembled in a single stack increases the heat-dissipating ability of the stack; the rating of plates is then 25 to 50% higher than those shown in Table I. Table II lists six selenium plates having the same

TABLE I

Plate Type No.	Diameter of Plates	Maximum Number of Plates per Stack	Max. R.M.S. Reverse Voltage per Plate	Single Phase Rectifiers			Three Phase Rectifiers			Rating of Plates Used as D.C. Valves	
				Half Wave	Bridge	Center Tap	Half Wave	Bridge	Center Tap		
	Inches		Volts	D.C. Amperes						Amperes	Volts
1	¾	36	18	.04	.075	.075	.10	.11	.13	.06	15
2	1	36	18	.075	.15	.15	.20	.225	.27	.12	15
3	1⅜	36	18	.15	.30	.30	.40	.45	.55	.23	15
4	1¾	40	18	.30	.60	.60	.80	.90	1.1	.45	15
5	2⅝	40	18	.60	1.2	1.2	1.6	1.8	2.2	.90	15
6	3⅜	40	16	1.2	2.4	2.4	3.2	3.6	4.5	1.8	12
7	4⅜	40	14	2.0	4.0	4.0	5.3	6.0	7.5	3.1	12

Current and Voltage Ratings of Seven Basic Selenium Plates When Used in Narrow Spacing Assemblies and with Resistive and Inductive Loads. For battery-charging and condenser loads, these ratings are reduced by 20 percent. Conditions: Continuous Duty; 35° C. Ambient Temperature.

TABLE II

Plate Type No.	Diameter of Plates	Maximum Number of Plates per Stack	Selenium Plate No. Used (See Table I)	Max. R.M.S. Reverse Voltage per Plate	Single Phase Rectifiers			Three Phase Rectifiers			Rating of Plates Used as D.C. Valves	
					Half Wave	Bridge	Center Tap	Half Wave	Bridge	Center Tap		
	Inches			Volts	D.C. Amperes						Amperes	Volts
20	1	28	2	18	.11	.22	.22	.29	.33	.4	.17	15
21	1⅜	28	3	18	.23	.45	.45	.6	.67	.82	.34	15
10	1¾	28	4	18	.39	.78	.78	1.0	1.1	1.4	.58	15
11	2⅝	28	5	18	.78	1.6	1.6	2.1	2.3	2.8	1.2	15
14	3⅜	28	6	16	1.5	3.1	3.1	4.1	4.6	5.8	2.4	12
18	4⅜	28	7	14	2.6	5.2	5.2	6.9	7.8	9.7	4.0	12

Current and Voltage Ratings of Six Selenium Plates (Similar to Table I, Except No. 1 Plate Omitted) When Used in Wide Spacing Assemblies and for Resistive and Inductive Loads. For battery-charging and condenser loads, these ratings are reduced by 20 percent. Conditions: Continuous Duty; 35° C. Ambient Temperature.

TABLE III

Plate Type No.	Size of Cooling Fins	Maximum Number of Plates per Stack	Selenium Plate No. Used (See Table I)	Max. R.M.S. Reverse Voltage per Plate	Single Phase Rectifiers			Three Phase Rectifiers			Rating of Plates Used as D.C. Valves	
					Half Wave	Bridge	Center Tap	Half Wave	Bridge	Center Tap		
	Inches			Volts	D.C. Amperes						Amperes	Volts
9	2⅝ D.	28	4	18	.58	1.1	1.1	1.5	1.7	2.1	.87	15
12	3⅜ D.	28	5	18	.90	1.8	1.8	2.4	2.7	3.3	1.4	15
13	4⅜ D.	28	5	18	1.1	2.2	2.2	2.9	3.3	4.0	1.7	15
15	4⅜ D.	28	6	16	1.8	3.5	3.5	4.6	5.2	6.5	2.7	12
16	4⅜ D.	24	6	16	1.9	3.8	3.8	5.0	5.6	7.0	2.9	12
17	6 × 6	28	6	16	2.7	5.4	5.4	7.2	8.1	10.0	4.1	12
19	6 × 6	28	7	14	3.7	7.4	7.4	9.8	11.1	13.3	5.7	12
8	8 × 8	28	7	14	5.0	10.0	10.0	13.0	15.0	18.0	7.5	12

Current and Voltage Ratings of Eight Selenium Plates (Nos. 4, 5, 6 and 7) Equipped with Cooling Fins of Different Sizes, and Used for Resistive and Inductive Loads. For battery-charging and condenser loads, these ratings are reduced by 20 percent. Conditions: Continuous Duty; 35° C. Ambient Temperature.

effective rectifying areas as those listed in Table I, but their current ratings are higher because of wider spacing.

By providing cooling fins, the forward current carrying capacity of the plates can be raised still further. Table III contains eight additional plates with fins, the current ratings of which are from two to two and one-half times greater than the plates of the same rectifying areas listed in Table I. With the extended ratings of the plates, whether by means of wide spacings or cooling fins, the internal losses of Selenium Rectifiers are greater; consequently, their efficiency is slightly reduced and the voltage regulation is adversely affected.

Tables I, II, and III also give the maximum permissible reverse r.m.s. voltages per plate. The voltages thus indicated have ample safety margin. If, however, the reverse voltage be increased beyond safe limits, the rectifying layer between the selenium and the front electrode alloy breaks down. The maximum specified voltage must not, therefore, be exceeded. Tables I, II, and III include ratings of selenium plates in d-c circuits.

Rectifier stacks with narrow or wide spacing, as well as those with fins, are ordinarily cooled by convection. Large size Selenium Rectifiers, however, often utilize forced draft ventilation in order to save space and to economize in rectifying elements. The normal plate rating can thereby be increased twofold, and sometimes threefold. If, however, extended loading of plates with the aid of forced ventilation is not desired, substantially greater current output, as compared with free air conditions, can be obtained by mounting the stacks in a chimney-like enclosure (Fig. 2). As

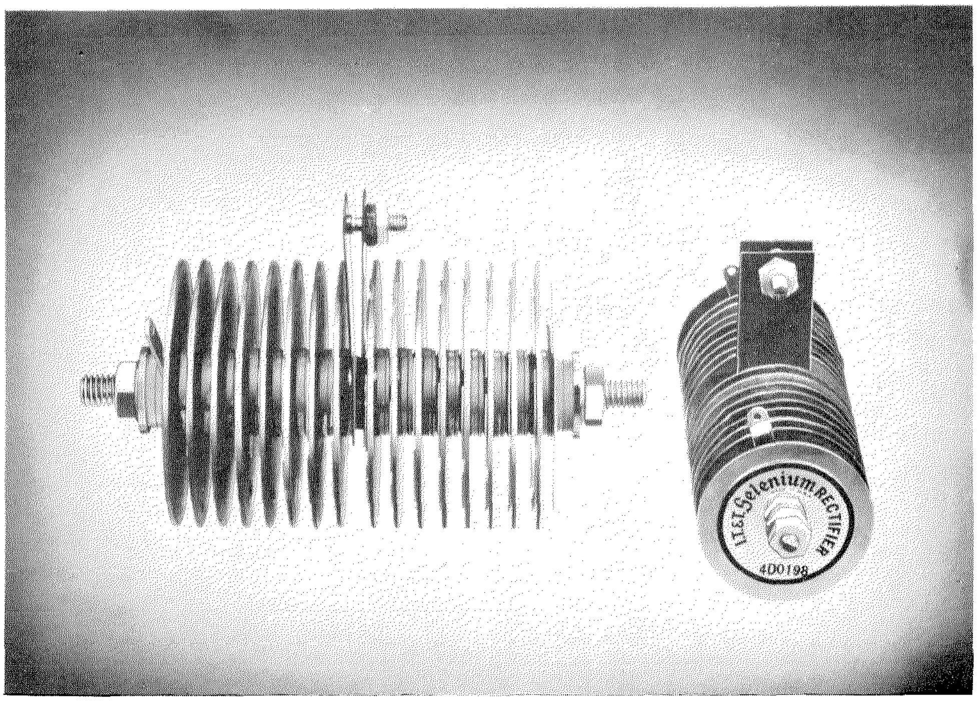


Fig. 3—Two Half Wave Selenium Rectifiers for Operation of Magnets in Business Machines. Both stacks are equipped with bi-metal strips to open the circuit when the plate temperature exceeds a specified value.

will be noted from the figure, the least favorable condition is that of mounting the stacks in a cabinet provided with perforated covers.

The current rating of Selenium Rectifiers is limited only by the final plate temperature resulting from heating. The stacks can be heavily overloaded, provided the maximum safe operating temperature of 75° C. is not exceeded. When this temperature is reached, the load must either be reduced to normal, or provision made for cutting the rectifying elements out of service as in the two half wave rectifiers illustrated in Fig. 3, widely used in business machines. Each element in these machines is equipped with a pair of bi-metal strips connected by means of an adjustable screw. If, by chance, the key-punch or the duplicator happens to be jammed and causes the temperature of the stacks to reach a range of 70 or 80° C., the bi-metal strips separate, thus breaking the circuit. The plates then cool off and the bi-metal strips again close (Fig. 4).

Intermittent Service

Considerable gain in the current capacity of Selenium Rectifiers can be obtained when they are used in intermittent service, in which case, the duty cycles must be definitely established. The variety of these intermittent applications is great and their complete discussion here would be too lengthy. One formula, however, is frequently used for periodic loadings:

$$I_m = I_{\text{max.}} \sqrt{\frac{A}{A+P}}\,, \qquad (1)$$

where I_m is the continuous current rating, $I_{\text{max.}}$ the maximum current drawn periodically, A the operating period, and P the inoperative interval; both A and P should be in the same time units. Experience has shown that this formula can be used only if A is less than the selenium plate time constant T, which may be defined by:

$$t_1 = t_2\left(1 - e\frac{A}{T}\right) \qquad (2)$$

and which varies from 5 to 8 minutes, depending on the plate size (t_1 and t_2 are instantaneous and final plate temperatures, respectively). When operating periods are separated by inoperative intervals of such length that the rectifier again cools practically to normal ambient temperature, much greater plate overloads are practicable.

Design of Stacks by Direct Values

After choosing the size of plate with proper current-carrying capacity, the internal voltage drop of the plate is considered. Fig. 5 illustrates the average, experimentally determined, internal voltage drop for seven plates in either bridge or center tap, single phase circuits. The voltage drop per plate, designated as *dv*, is one-half of the difference between the root mean square values of voltages read on the input and output side of the rectifier. These quantities are plotted as ordinates against the arithmetical values of output current in amperes plotted as abscissa.

The output voltage of a Selenium Rectifier is determined by the input voltage V_{ac} less the total voltage drop within the rectifier. The computation of the necessary alternating current voltage to be impressed on the Selenium Rectifier involves consideration of the voltage drop per plate and the number of plates through which the current flows.

Using the data given in Tables I, II, and III, and the internal voltage drop per plate illustrated in Fig. 5, any single phase Selenium Rectifier can be designed and the necessary alternating current voltage computed by the following formula:

$$V_{ac} = k_1 V_{dc} + k_2 n dv, \qquad (3)$$

where V_{ac} is the input voltage, k_1 the form factor to convert the arithmetical value to the root mean square voltage value (Table IV), V_{dc} the required direct current output voltage, k_2 the number of arms through which current must pass in the circuit for each half-cycle, n the number of plates in series per arm, and dv the voltage drop per plate for the circuit employed. The constants k_1 and k_2 vary depending upon whether a bridge or center tap connection, a single or three phase circuit is employed.

As an example, let us design a bridge type unit required to deliver 4 amperes at 16 volts continuously under the maximum ambient temperature of 35° C. in a single phase circuit. Selenium plate No. 7, $4\frac{3}{8}''$ in diameter (listed in Table I and rated at 4 amperes) will serve the purpose. Using equation (3) and corresponding constants from Table IV:

$$V_{ac} = 1.15 \times 16 + 2ndv.$$

The number of plates in series, i.e., quantity n, necessary at this stage, can be computed by the following formula:

$$n = \frac{k_1 V_{dc}}{V_p - 2dv}. \qquad (4)$$

V_p for Plate No. 7 is 14, and dv, as read off characteristic No. 7 in Fig. 5, is 1.29; hence,

$$n = \frac{1.15 \times 16}{14 - 2 \times 1.29} = 1.6 \text{ or 2 of No. 7 plates in series.}$$

V_{ac}, therefore, at the start of service, is equal to 23.6 volts. With the aging of the Selenium Rectifier, the forward resistance increases and the inverse resistance also slightly increases. Based on lengthy experience in the design and application of these rectifiers it can be stated that the only variable in equation (3) is dv, which may increase as much as 50% under most adverse conditions. An additional tap, therefore, should be provided in the transformer winding to give the V_{ac} required for the aged condition:

$$V_{ac} = 1.15 \times 16 + 2 \times 2 \times 1.29 \times 1.5 = 26 \text{ volts.}$$

Designs by Relative Values

The foregoing example and reference to Fig. 5 characteristics apply only to the single phase, bridge, and center tap designs with either inductive or resistive loads. With condenser and

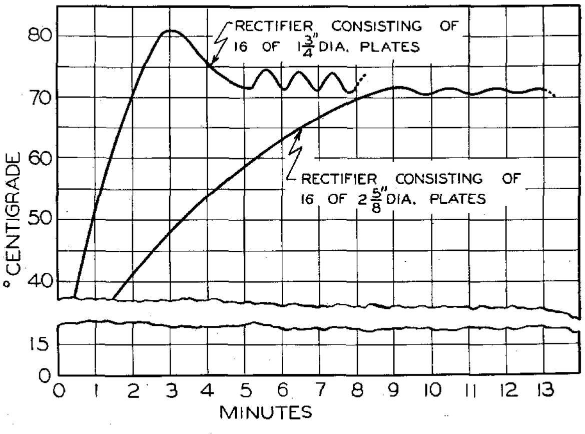


Fig. 4—Time-Temperature Characteristics Illustrating the Performance of Selenium Rectifiers Equipped with Bi-Metal Strips (Fig. 3).

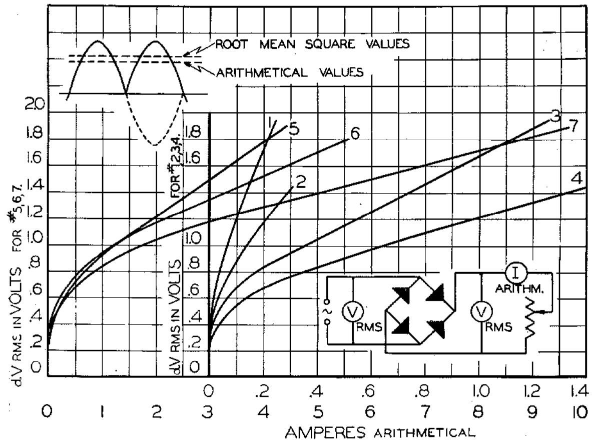


Fig. 5—Rectification Characteristics of Seven Basic Plates ($\frac{3}{4}$, 1, $1\frac{3}{8}$, $1\frac{3}{4}$, $2\frac{5}{8}$, $3\frac{3}{8}$ and $4\frac{3}{8}$ inch Diameter) Used in the Design of Single Phase Bridge and Center Tap Rectifiers for Inductive and Resistive Loads.

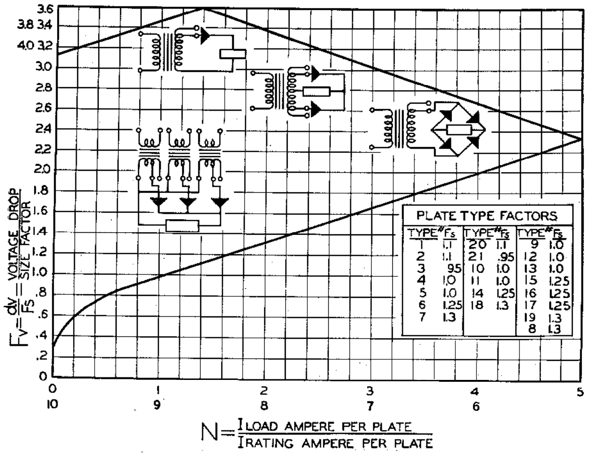


Fig. 6—Characteristic Illustrating the Relation of F_v and N for Single Phase, Half Wave, Center Tap and Bridge Rectifier Circuits with Resistive or Inductive Load; Also for Three Phase, Half Wave Rectifier Circuit with All Types of Load.

battery charging loads, even in the above-mentioned circuits, intermittent loading on the selenium plates occurs with periodic values of the forward current greater than the periodic values for the same d-c output feeding resistive or inductive load; voltage drops per plate are, therefore, greater in the former case. Applications occur, however, where the voltage drop per plate is smaller than the values shown in Fig. 5. An example is the three-phase circuit where the rectified current is practically at the peak value of the applied alternating current. The output current density per plate in these circuits is considerably higher than in the case of a single phase bridge circuit; furthermore, the type of load, whether it be resistive, inductive, capacitive, or battery charging, has practically no effect on the voltage drop per plate.

Inasmuch as a wide variety of circuits and types of loading is encountered, a method for rating the 21 rectifier types according to relative values of output current and voltage drop per plate has been developed. Figs. 6, 7, 8, and 9 illustrate the relationships N and F_v for various types of circuits and loads.

The use of these characteristics involves, first, determination of the value N, which is obtained by dividing the actual ampere load per plate by the ampere rating of the basic plate employed. With this value determined, the value F_v is read from one of the characteristics and then multiplied by the plate size factor F_s to obtain the actual voltage drop per plate, dv, for the plate selected.

Fig. 6 illustrates the relationship of F_v to the value N for half wave, center tap and bridge, single phase circuits when loaded with either resistive or inductive load; also for half wave, three phase circuits for all types of loads. Fig. 7 gives a similar relationship of F_v to the value N for half wave, center tap and bridge circuits, all single phase for capacitive or battery charging applications. Fig. 8 shows the relationship of F_v to N for three phase bridge and center tap circuits for all types of loads. Finally, Fig. 9 shows the relationship of F_v to N for direct current and blocking circuit applications.

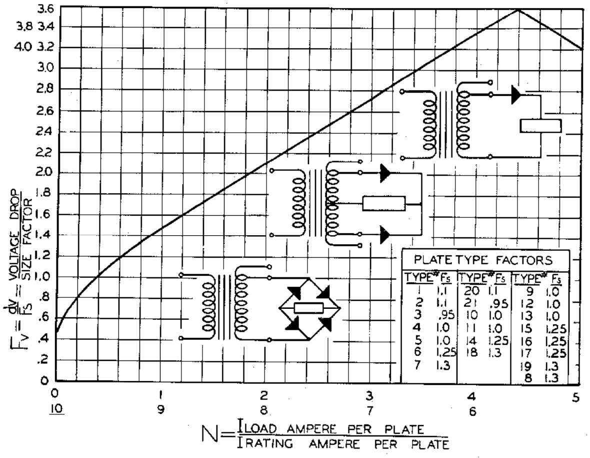


Fig. 7—Characteristic Illustrating the Relation of F_v and N for Single Phase, Half Wave, Center Tap and Bridge Rectifier Circuits for Battery-Charging Application or Condenser Loads.

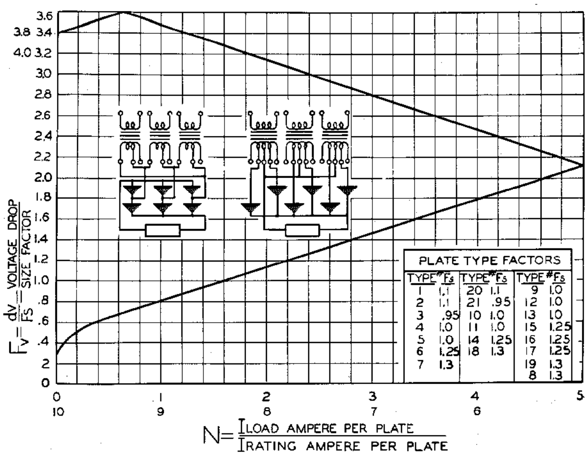


Fig. 8—Characteristic Illustrating the Relation of F_v and N for Three Phase, Center Tap and Bridge Rectifier Circuits for All Types of Load.

To illustrate this method of design, let us compute a three phase Selenium Rectifier capable of delivering 325 amperes at 13 volts for the filament supply of a television transmitter tube. An additional requirement is that the rectifier deliver not more than 488 amperes at approximately 2 volts into the tube when cold.

Several plates in Tables I, II, and III should be tried; however, plate No. 13, rated at 3.3 amperes will be most economical; the total current of 325 amperes can be safely handled by 100 plates connected in parallel.

$$I_{dc}=\frac{325}{100}=3.25 \text{ amperes per plate.}$$

This plate loading with 1.8 ampere rating for basic plate No. 5 used in type No. 13 will give:

$$N=\frac{3.25}{1.8}=1.8.$$

From Figure 8, $F_v=1.07$ and $dv=1.07\times1=1.07$.

In aging, the dv value may increase 50%, and thus becomes 1.6. Substituting the known quantities in formula (4):

$$n=\frac{.74\times13}{18-2\times1.6}=.65; \text{ or 1 plate in series.}$$

The foregoing proves that the entire rectifier should consist of a total connection of (6–1–100), where the first number (6) designates the number of arms of the three phase circuit, the second number (1) indicates the number of plates in series, and the third number (100) gives the number of plates in parallel. The total of 600 plates of type No. 13 may be conveniently assembled into 24 stacks, each having 25 plates in parallel.

Using formula (3) and the design constants of Table IV:

$$V_{ac}=.74\times13+2\times1\times1.07=11.8 \text{ volts}$$

when rectifying elements are new;

$$V_{ac}=.74\times13+2\times1\times1.6=12.8 \text{ volts}$$

when they are fully aged.

In order to meet the requirements of approximately 2 volts with the current output of 488 amperes:

$$I_{dc}=\frac{488}{100}=4.88 \text{ amperes per plate;}$$

$$N=\frac{4.88}{1.8}=2.7;$$

from the characteristic of Fig. 8,

$$F_v=1.37.$$

For the new stacks, therefore, $dv=1.37\times1=1.37$, and for fully aged stacks:

$$dv=1.37\times1.5=2.06.$$

Using formula (3) and these two values of dv, the new and aged V_{ac} will be found to be 4.2 and 5.6 volts, respectively. The 50% limit for the current requirement is actually met by the external limiting reactances in each phase of the three phase circuit. The complete assembly of this rectifier is shown in Fig. 10.

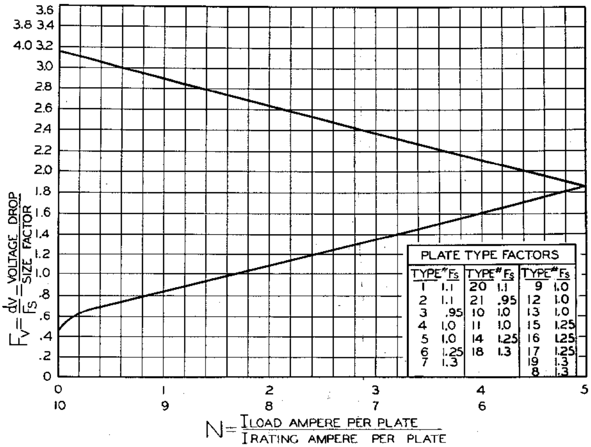


Fig. 9—Characteristic Illustrating the Relation of F_v and N for Direct Current and Blocking Circuits.

The ordinary single phase bridge type rectifier for resistive loading can also be designed through the use of relative values. Fig. 11 illustrates a 2-ampere, 120-volt Telautograph unit.

With two No. 9 plates in parallel, or one ampere per plate:

$$N=\frac{1}{.6}=1.67;$$

from the characteristic of Fig. 6,

$$F_v=1.2;$$
$$dv=1.2\times 1.0=1.2;$$

hence,

$$n=\frac{1.15\times 120}{18-2\times 1.2\times 1.5}=9.6, \text{ or 10 plates in series.}$$

The total connection of the rectifier is then 4–10–2. Practical considerations suggest four stacks, two of which make one bridge with ten plates in each arm of the bridge. Again, from formula (3), corresponding constants of Table IV and the above *dv* value, V_{ac} is found to be 162 volts when new and 174 volts when aged.

TABLE IV

Number of Phases	Circuit Type	k_1	n	k_2
1	Half Wave	2.3	$\frac{V_{ac}}{V_p}$	1
1	Bridge	1.15	$\frac{V_{ac}}{V_p}$	2
1	Center Tap	1.15	$\frac{2V_{ac}}{V_p}$	1
3	Half Wave	.855	$\frac{\sqrt{3}V_{ac}}{V_p}$	1
3	Bridge	.74	$\frac{V_{ac}}{V_p}$	2
3	Center Tap	.74	$\frac{2V_{ac}}{V_p}$	1

Selenium Rectifier Design Constants: k_1*=form factor;* n*=number of plates in series;* k_2*=circuit factor;* V_p*=maximum voltage per plate;* V_{ac}*=phase voltage, except three phase bridge where it is line voltage.*

Ratings (Tables I, II, and III) of Selenium Rectifier plates, functioning as blocking valves in direct current circuits, are higher in current and lower in voltage value than they are in half wave alternating circuits. The higher current rating is acceptable inasmuch as the forward resistance ordinarily decreases when only forward current passes through the Selenium Rectifier plates. The reverse current of the blocking unit, on the other hand, is higher and the safe voltage limit is, therefore, more conservatively established than for alternating current circuits. As an example, a 30 volt, 4.5-ampere blocking unit consists of a total connection of 1–2–5 No. 5 plates. The value *N* for this unit is equal to one, and *dv* is .84 (Fig. 9).

Experience has shown that for constant current battery charging and condenser loading, the current rating should be only 80% of the values tabulated in Tables I, II, and III. In the design of the rectifier for charging a 60-cell battery at the rate of 0.4 ampere, with 2.4 volts per cell, plate No. 4 may be selected. The value of *N* is .67. The new *dv*, as read off the characteristic of Fig. 7, is 1.25 and, after aging, it becomes 1.87. The number of plates in series is determined either by

$$n=\frac{V_b}{V_p} \text{ or} \qquad (5)$$

$$n=\frac{V_b/\sqrt{2}}{V_p-2dv} \qquad (6)$$

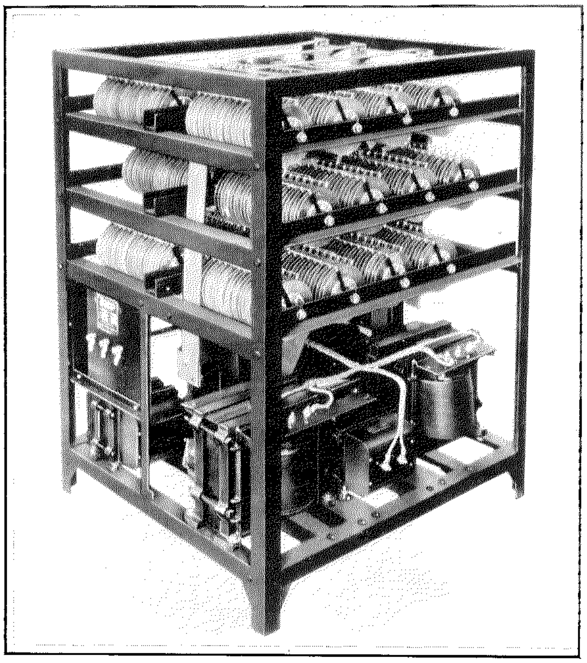


Fig. 10—Rectifier Unit of 325 Ampere, 13 Volt Rating with Reactances Limiting Output Current to 488 Amperes at 2 Volts. A.C. Input: 220 volts, three phase, 60 cycle. Rectifying element consists of 600 plates arranged in 24 stacks, each stack consisting of 25 plates in parallel.

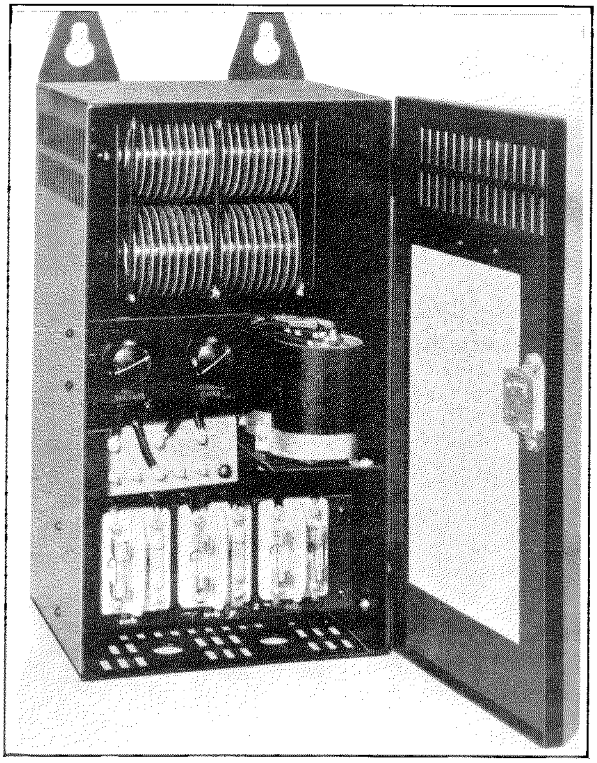


Fig. 11—Selenium Rectifier with Output of 2 Amperes at 120 volts for Powering Telautograph Equipment.

depending on which is greater.

$$V_{ac}=\frac{V_b}{\sqrt{2}}+k_2ndv \qquad (7)$$

$$=\frac{60\times 2.4}{\sqrt{2}}+2\times 8\times 1.25=122 \text{ volts}$$

An additional tap to give 132 volts for the fully aged condition of the stacks should be provided.

Design of Forced Draft Ventilation Unit

The extended current rating of Selenium Rectifier plates with forced draft or fan cooling and the speed of air constituting the forced ventilation require further consideration. A rather conservative relationship of current rating to air velocity has been established and successfully used for the 4$\frac{3}{8}$″ diameter No. 7 plate (Table V).

As an example, let us design a three phase, full wave rectifier supplying a d-c output of 600 amperes at 6 volts. Because of the low required output voltage, as compared to the full r.m.s. voltage permissible for the No. 7 plate, the center tap circuit is most economical and gives greatest efficiency. With the fan delivering air at a speed of 120 feet per minute, the 7.5 ampere (Table I) loading of this plate can be increased 2.5 times (Table V), thus making it 18.7 amperes per plate. Practical consideration of possible 10% overload suggests that this unit should have 36 plates in parallel for the total current output of the unit. This makes the value N (Fig. 8) equal to 2.22 and the initial and aged dv equal to 1.6 and 2.4, respectively. The total connection of the rectifier is, therefore, 6–1–36. The new V_{ac} for half of the transformer secondary voltage is 6.1 volts and, for the fully aged condition, 6.9 volts. A view of this equipment is shown in Fig. 12.

Voltage Regulation

The inherent voltage regulation of the Selenium Rectifier is in the neighborhood of 10–20%. In computing the regulation, one must determine the no load value of dv and then the no load output voltage. In the case of the first example of a 4 ampere, 16 volt rectifier, the dv value from Fig. 5 is 0.4. The d-c output voltage, therefore, at no load is:

$$V_{dc}=\frac{23.6-2\times 2\times .4}{1.15}=19.1,$$

$$\text{Regulation}=\frac{19.1-16}{16}\times 100=19.4\%.$$

Similarly, the regulation of the three phase, 325 ampere, 13 volt unit (Fig. 10) is computed by reading F_v for N equal to zero in Fig. 8. Substituting 0.3 for the value of dv in formula (3), and taking 11.8 volts for V_{ac}, the no load voltage is

TABLE V

Multiplying Factor for Normal Plate Ratings, k_3	1	1.5	2	2.5	3	3.5	4	4.5
Air Speed in Ft. per Minute	0	60	90	120	160	200	310	400
Cubic Feet per Minute per Plate	0	.5	.8	1.1	1.4	1.7	2.8	3.7

Relation of Factor k_3 by Which Normal Rating of No. 7, i.e. 4$\frac{3}{8}$ Diameter Selenium Plates Can Be Increased, and the Speed and Amount of Air Necessary.

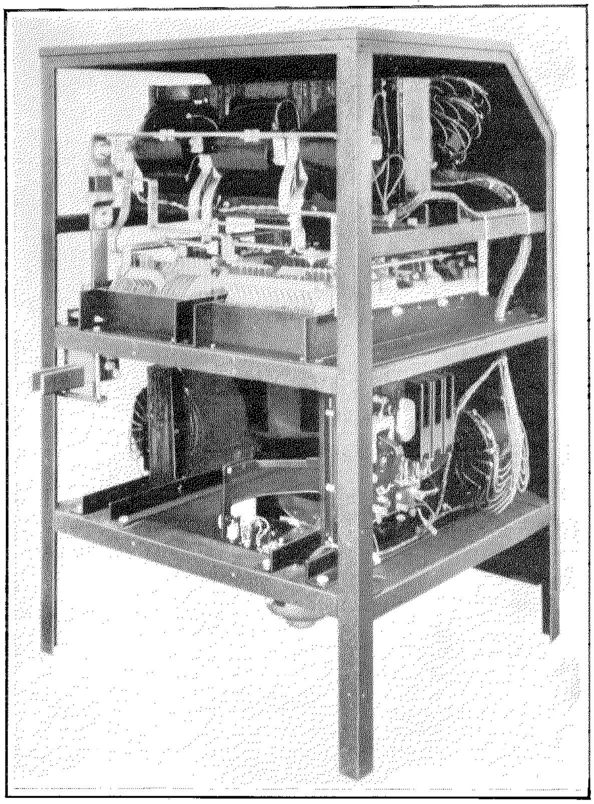


Fig. 12—Three Phase Selenium Rectifier Unit Employing Forced Draft Ventilation for Output of 600 Amperes at 6 Volts. Overall Efficiency: 74%; Power Factor: 94%.

found to be 15 volts, and the voltage regulation is, therefore, 15.4%.

Efficiency

The efficiency of Selenium Rectifiers varies with the type of circuit and the nature of the load. The single phase circuits with fully loaded plates in respect to voltage and current, and when feeding either resistive or inductive loads, give an efficiency of approximately 64%; the same circuits, when used for battery charging, give an efficiency some 14% higher due to the greater value of the rectified voltage. The three phase circuits give efficiency values in the neighborhood of 83% and, for all practical purposes, remain the same irrespective of the type of load. For all circuits and loads, however, the efficiency of Selenium Rectifiers increases with decrease of load down to approximately 25% of full value, and thereafter falls off rapidly. The efficiency itself depends on the combined losses in the Selenium Rectifier from forward and reverse currents, and, in formula form, it is:

$$\frac{V_{dc}I_{dc}}{(V_{dc}I_{dc})+W_f+W_r}\times 100=\%\text{ efficiency}, \qquad (8)$$

where W_f are losses due to forward current and W_r are losses due to the reverse current.

The computation of exact efficiency for all sizes of plates, and various loads and circuits is rather involved and constitutes an extensive subject in itself.

In order to illustrate the simplified method of efficiency computation and the effect of *dv* changes on its value, let us compute the efficiency of the 325 ampere, 13 volt, three phase unit illustrated in Fig. 10.

Forward losses per plate in the three phase bridge circuit are

$$w_f=\frac{\sqrt{2}I_{dc}dv}{3},$$

where $\sqrt{2}$ is a conversion factor for approximating the peak value of the a-c wave in terms of effective value of *dv*. Divisor 3 results from the fact that in the three phase bridge circuit each plate is utilized $2\times 1/6$ times in each cycle.

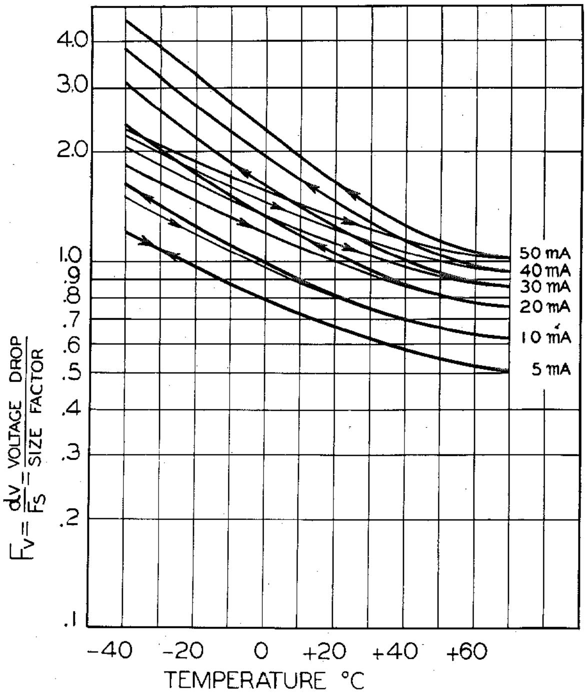


Fig. 13—Relation of F_v at Varying Current Densities to the Ambient Temperatures Throughout a Heating and Cooling Cycle.

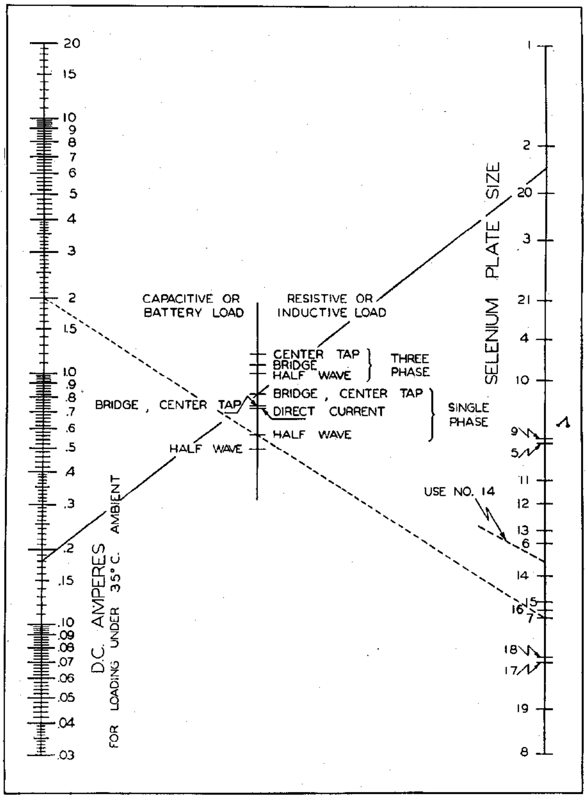


Fig. 14—Alignment Chart for Determining the Rectifier Type Number for: (1) Output Current, (2) Nature of Load, (3) Type of Circuit.

$$w_f = \frac{325/100 \times \sqrt{2} \times 1.07}{3} = 1.64 \text{ watts per plate,}$$

or $W_f = 6 \times 100 \times 1.64 = 984$ watts for all 100 plates in six arms.

The reverse losses are approximately one third of forward losses computed for the normal rating of the plate used in this unit:

$$W_r = \frac{1}{3} \times \frac{6 \times 100 \times .8 \times \sqrt{2} \times 1.8}{3} = 136 \text{ watts.}$$

The new input wattage W, therefore, is:

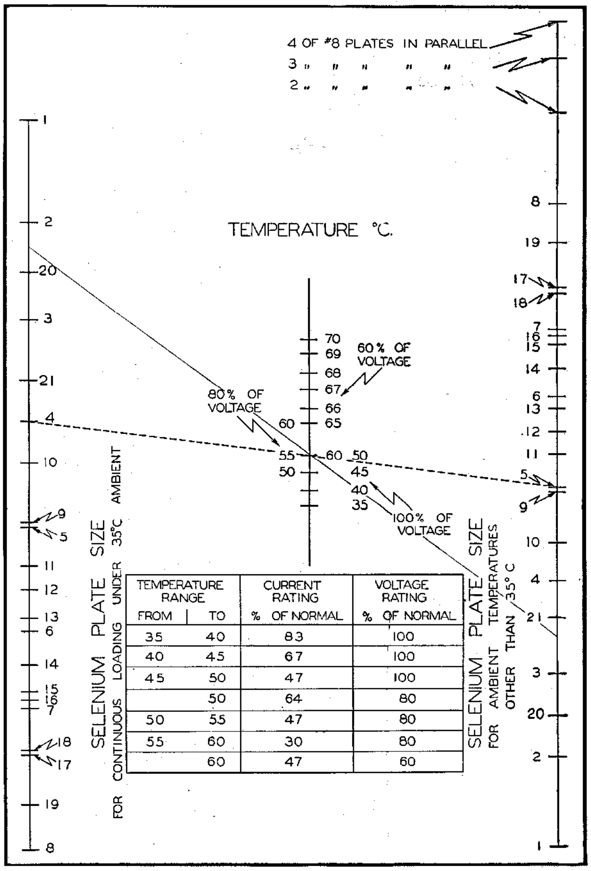
$$W = (I_{dc} \times V_{dc}) + W_f + W_r$$

$$= (325 \times 13) + 984 + 136 = 5345 \text{ watts.}$$

$$\text{Efficiency} = \frac{4225}{5345} \times 100 = 79.2\%.$$

Similarly, assuming a possible 50% change in dv, the efficiency of this rectifier with stacks fully aged is computed as 72%.

The foregoing designs illustrate the importance of the quantity dv, which is dependent on the forward resistance and current density of the plates as well as the ambient temperature under operating conditions. Its changing values under varying conditions greatly influence the efficiency, regulation, and aging of Selenium Rectifiers. The ambient temperature and current density relationships affecting the value of dv are illustrated in Fig. 13. The arrows on the curves indicate that the resistance of the plates decreases with increase of temperature. As the plates cool off the resistance again increases, and dv is greater at the new lower temperatures than during the rising temperature phase of the heating cycle. This phenomenon diminishes with lower current densities to a point where the resistance is the same at corresponding temperatures of the heating and cooling portions of the cycle.



TEMPERATURE RANGE FROM	TEMPERATURE RANGE TO	CURRENT RATING % OF NORMAL	VOLTAGE RATING % OF NORMAL
35	40	83	100
40	45	67	100
45	50	47	100
	50	64	80
50	55	47	80
55	60	30	80
	60	47	60

Fig. 15—Alignment Chart for Determining the Selenium Rectifier Plate Type Number Required in Ambient Temperatures Above 35° C. Also, Table of Percentage of Current and Voltage Ratings at Ambient Temperatures Above 35° C.

Selection of Plate Type for 35° C. and Higher Ambient Temperature

Almost invariably more than one selenium plate type appears suitable for given output requirements. The type of circuit or nature of loading as well as the cost, however, restricts the choice.

The Alignment Chart (Fig. 14) has been found useful in selecting plate types for specified output currents. If a straight edge is laid connecting the required direct current output with the type of circuit and the nature of load, the intersection of the straight edge on the plate size scale gives the type number of the required rectifier plate. If the intersection falls between two plate type numbers, the plate having the higher current rating should be chosen.

For ambient temperatures higher than 35° C., the plate type number for a 35° C. ambient should first be found. Referring to Fig. 15, a straight edge connecting the 35° C. ambient temperature plate type number with the desired higher ambient value of the temperature scale intersects the right-hand scale, indicating the required higher ambient plate type number. Again, if the intersection is between two plate type numbers, the plate type number with the higher current rating should be used. It will be noted that, by decreasing the voltage rating, a small increase in current rating is allowable.

As an example, let us design a high voltage, low current rectifier of the type illustrated in Fig. 16 for either resistive or inductive load. Referring to Fig. 14, the line drawn through the 0.18 reading on the left-hand scale, and the point marked "single phase bridge" in the middle of the chart, intersects the right-hand scale between "2" and "20". Thus, Plate 20 (Table II) would be used if the rectifier is to operate under maximum ambient temperature of 35° C. In order to derate plate 20 for a 60° C. ambient, reference is made to Fig. 15. The line drawn on this chart through the same point (between "2" and "20") of the left-hand scale (as in Fig. 14) and the point marked "60% of voltage" indicates that the No. 21 selenium plate (Table II) should be used for the required assembly. Further computations of quantities N, dv, and n result in the design of a rectifier with total connections of 4–224–1, arranged in 28 stacks, each consisting of 32 $1\frac{3}{8}''$ plates in series.

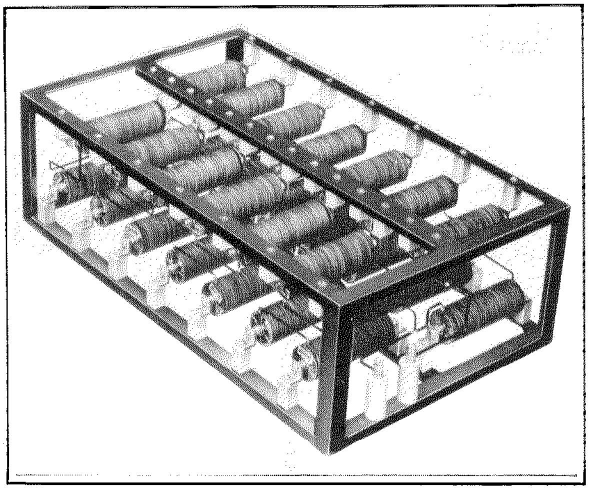


Fig. 16—Single Phase Bridge Connected Rectifier. Output: 180 Milliamperes at 2300 Volts Under Ambient Temperatures from −40° C. to +60° C.

Bibliography

1. "Selenium Rectifier Characteristics, Application and Design Factors," by C. A. Clarke, *El. Com.*, Vol. 20, No. 1, 1941.
2. "Selenium Rectifiers for Closely Regulated Voltages," by J. E. Yarmack, *El. Com.*, Vol. 20, No. 2, 1941; *Electronics*, Sept., 1941.
3. "The Characteristics and Applications of the Selenium Rectifier," by E. A. Richards, *Journal I.E.E.*, Vol. 88, Part II, No. 5, October, 1941.
4. "Le Redresseur au Sélénium et ses applications dans la technique des courants faibles," by E. Frey, *Bul. Technique*, Berne, No. 5, 1941.
5. "Some Industrial Applications of Selenium Rectifiers," by S. V. C. Scruby and H. E. Giroz, *El. Com.*, Vol. 17, No. 4, 1939.
6. "Rectifier Power Plant for Transmission Systems," by R. Kelly, *El. Com.*, Vol. 18, No. 1, 1939.
7. "Selenium Rectifier for Signaling," by J. E. Yarmack and C. G. Howard, *Railway Signaling*, Vol. 32, No. 12, December, 1939.

The Electrical Strength of Nitrogen and Freon Under Pressure*

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Editor's Note

The work reported in this paper continues studies of the electric strength of air for the primary purpose of investigating the electric strength of the gas dichlorodifluoromethane, commonly known as Freon F-12. It was carried on by the Electrical Engineering Department of Stanford University under the sponsorship of the International Telephone and Telegraph Corporation.

Synopsis

Results are given of an investigation of the electric strength of nitrogen, of dichlorodifluoromethane (Freon F-12), and of mixtures of these gases. Sparking voltages are presented as measured between spherical electrodes of brass and aluminum and between pointed electrodes of brass, at various spacings and in gas at pressures ranging from one to several atmospheres. All measurements are for 60-cycle applied voltage. Dichlorodifluoromethane is found to withstand much higher voltages than either air or nitrogen; this advantage is more marked between points than between spheres, which suggests its use in certain types of insulation applications. A small percentage of dichlorodifluoromethane gas in nitrogen produces an anomalously large rise in the electric strength of the gas, indicating practical advantages of such mixtures.

PREVIOUS studies of the electric strength of air under pressure have been reported by the authors.[1,2] The present paper presents data from a continuation of this work for the primary purpose of studying the electric strength of the gas dichlorodifluoromethane, CCl_2F_2, commonly known as Freon F-12. This gas is readily available as a refrigerant and is known to have unusually high electric strength. It was studied both alone and mixed with nitrogen, and to complete the series of tests the electric strength of nitrogen was also determined.

Freon was obtained in liquid form, in a pressure cylinder, and gas from the upper part of the cylinder was released into the test chamber as desired. Nitrogen gas of commercial purity was used; it is guaranteed 95% pure but is believed to be purer than the guaranteed value. It is supplied under pressure, and was released into the test chamber when needed. No purification of either gas was attempted, for it was believed that results obtained with gas of commercial purity would be more significant from an engineering point of view than results obtained with chemically pure gases. In the present investigation no irregularities or inconsistencies of data could be traced to the presence of impurities in the gases supplied.

The apparatus used is described and pictured in a previous publication.[2] The methods of measurement and technique employed in the study of Freon were the same as in the previous work with air, except as the use of mixed gases required special methods.

In order to obtain mixtures of gases of known composition for test purposes, it was necessary to evacuate the test chamber before admitting the gas or gases in which the test was to be performed. Pressure within the chamber was reduced by means of a vacuum pump to a value estimated at one millimeter of mercury before admitting nitrogen or Freon. By this means practically all of the residual gases were removed. This was particularly necessary for the purpose of removing all traces of Freon gas before testing in an atmosphere supposed to contain no Freon. The presence of an extremely small amount of Freon in nitrogen or air was found to be important in determining dielectric strength, sometimes increasing the sparking voltage by fifty per

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* Paper presented at the Winter Convention of the A.I.E.E. in New York, N. Y., Jan. 26–30, 1942. Reprinted from *A.I.E.E. Transactions*, Vol. 61, 1942, April Section.

cent or more, although the amount of Freon could hardly have been more than a fraction of a per cent. The sparking voltage in such cases was highly erratic and undependable. Similar results were obtained when a trace of carbon tetrachloride was present in the test chamber.

After a series of tests with Freon, it was found best for the test chamber to be evacuated and left for several hours or days. Nitrogen was then admitted to the chamber, and it was again evacuated. This process removed all indication of the presence of Freon in subsequent tests.

In order to obtain satisfactory mixing of gases when Freon and nitrogen were used together, it was found necessary to stir the gases with an electric fan placed within the test chamber. Natural mixing by diffusion did not take place in the course of several hours. When the fan was not used, the heavier Freon went to the bottom of the test chamber and remained partially unmixed with the nitrogen. Results without use of the fan were inconsistent and meaningless. Less than five minutes of operation of the fan was adequate to give thorough mixture of the gases, and results obtained with its use were consistent and could be repeated from day to day.

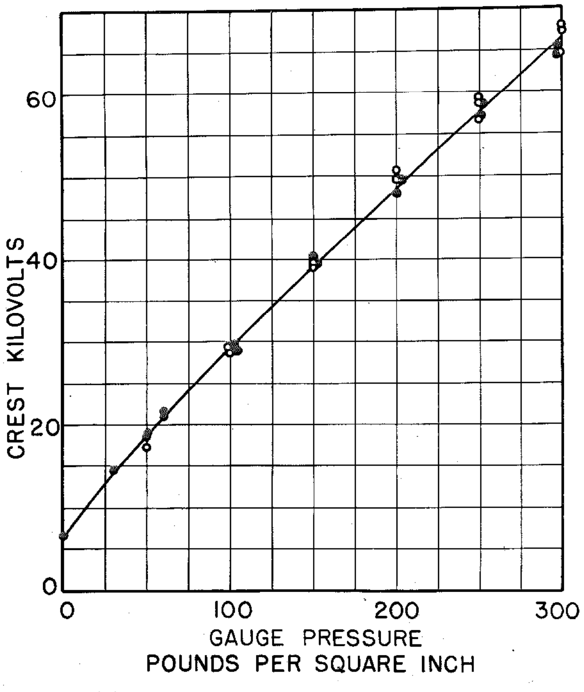

Fig. 1—Comparison of Sparking Voltages in Air and Nitrogen.

Spherical electrodes
Length of spark gap: 0.050 inch
○ *Experimental points in air*
● *Experimental points in nitrogen*

For test of sparking between spherical electrodes in gas mixtures containing Freon, aluminum electrodes were used in most cases. Aluminum was used because of its greater resistance to corrosive action under such circumstances. Brass was less resistant than aluminum, and steel was less resistant than brass. It is presumably not Freon itself that is harmful to the metal electrodes, for it is reported—in publications relating to its chemical properties—to be noncorrosive, and it is used satisfactorily for refrigeration. Electric discharge in Freon, however, is reported to produce chlorine and other corrosive products of decomposition. It is apparent from the present investigation that the products of electrical discharge in Freon are distinctly corrosive. Moreover, products of electric discharge in a mixture of Freon and air are very considerably more corrosive than those that result from Freon alone or in mixtures of Freon and nitrogen. Corrosion of electrodes in mixtures of Freon and nitrogen was about as severe as in pure Freon, and very much less than in mixtures of Freon and air.

Sparking in nitrogen was remarkably free from corrosion of any kind, and hundreds of sparks would barely tarnish the polished surface of either brass or aluminum spheres. Pointed brass electrodes lost none of their original sharpness after forty or fifty sparks in nitrogen, whereas they were noticeably rounded and measurably shortened in length by similar sparking in either air or Freon.

Results in Nitrogen

In general, sparking voltages between spheres in nitrogen are the same as between spheres in air. This conclusion was checked carefully with an 0.050-inch gap at pressures from 1 to 21 atmospheres; sparking voltages in nitrogen could not be distinguished from those in air (see Fig. 1).

A careful study of sparking between spheres at various spacings and pressures had been made in air,[2] and because of the similarity of results this was not repeated in nitrogen.

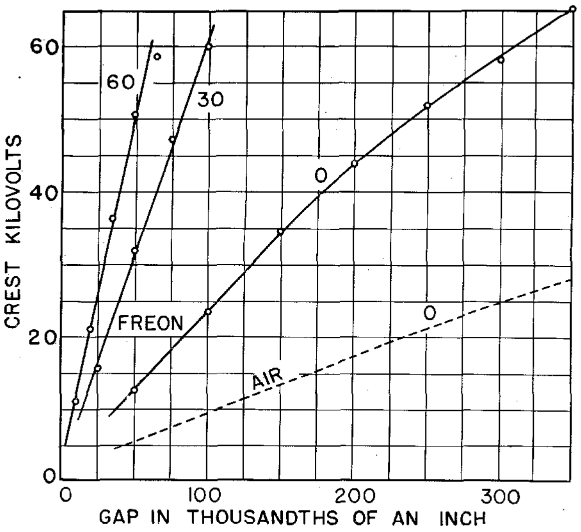

Fig. 2—Sparking Voltages in Freon.

Spherical electrodes
Gauge pressure in pounds per square inch as noted on curves

Despite the general agreement observed between sparking between spheres in air and in nitrogen, there were certain differences in detail. It has been mentioned[1,2] that in air there was a tendency for the sparking voltage to rise slightly as a number of measurements were made in rapid succession. No such result was noticed in nitrogen. It has also been mentioned that a spark would usually result in air if voltage was held for a period of several minutes at a value as much as five to seven per cent below the usual sparking value. This effect did not appear in nitrogen. The sparking values given in this report for nitrogen are average values. Most of the individual sparking values for pure nitrogen lie within one per cent of the average value, the most extreme variations being about five per cent.

It should be emphasized that a slight trace of Freon in the nitrogen would cause very erratic results, but that clean nitrogen was quite consistent.

Results in Freon

Sparking in Freon was investigated at pressures of from one atmosphere to about six atmospheres, with gaps varying from 10 mils to 250 mils (0.010 to 0.250 inch) between both brass and aluminum spheres. Sparking between points was also studied (see following). The highest pressure possible at room temperature was about six atmospheres, at which pressure the gas is in equilibrium with liquid Freon. (The vapor pressure of Freon at 70 degrees Fahrenheit is 84.82 pounds per square inch absolute, 70.12 pounds per square inch gauge.[5])

Freon was found to have a sparking voltage between spheres that was, for all pressures investigated, between 2 and $2\frac{1}{2}$ times as great as the sparking voltage in nitrogen or air at the same spacing and pressure (see Fig. 2).

The nature of the spark in Freon was not noticeably different from the sparks observed in air and nitrogen, except in color. Sparks in Freon are intensely blue, in nitrogen they are purple, and in air white or slightly yellow. The intensity of sparks in the different gases, however, appears to be much the same when due allowance is made for the amount of current flowing.

Values of sparking voltage obtained in Freon were fairly consistent, although a variation of two or three per cent from the average value was not uncommon. Variations of as much as ten per cent were occasionally encountered, usually below the average sparking voltage rather than above. No "trends" of voltage values, as found in air,[2] were discovered in Freon, and there were no sparks at voltages radically different from the average value.

In general, sparking voltage between spheres in Freon was found to be proportional to the length of gap, and proportional to the pressure of the Freon gas. To be more precise, the voltage-spacing and voltage-pressure relations were found to be linear, but not exactly proportional, taking the same form as Paschen's law for sparking in air.

The breakdown voltage of Freon as determined in the present investigation can be expressed by the formula

$$V = 183PS + 4.0,$$

where V is sparking voltage in kilovolts, P is pressure in atmospheres, and S is spacing in inches. It will be seen that this equation gives voltage values for sparking in Freon between 2.4 and 2.5 times the values given by Paschen's law for air.[2]

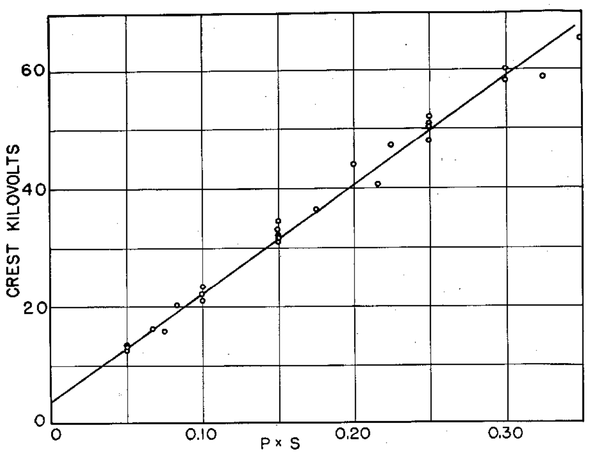

Fig. 3—Sparking Voltages in Freon.
Spherical electrodes
Points are experimental; line is computed from $V=183PS+4.0$ *kilovolts*
P_1 *absolute pressure in atmospheres*
S_1 *spark-gap length in inches*

The preceding formula appears to be reasonably accurate over the range of conditions of test. The values of sparking voltage obtained by experiment, each an average of five to ten individual voltage readings, are all within ten per cent of the value given by the formula. The experimental range of pressure was from one to five atmospheres, and the range of spark length was from 10 to 350 mils, giving a range of the product PS from 0.05 to 0.35 (atmosphere-inch). This is shown in Fig. 3. This formula was derived from the authors' results alone. However, it was found to give good agreement with the sparking voltages measured between flat electrodes in Freon by Trump, Safford, and Cloud (see Figs. 3 and 4 of reference 9), for pressures up to about four atmospheres (60 pounds per square inch absolute). As the vapor-pressure of Freon is approached (six atmospheres at room temperature) the experimental sparking voltages are lower than would be expected from the formula. Agreement with the work of Trump, Safford, and Cloud appears to extend the range of applicability of the formula to direct voltage as well as alternating, to gap lengths as great as 0.7-inch, and to values of the product PS as great as 2.0 (atmosphere-inches).

Results in Freon-Nitrogen Mixtures

The electric strength of mixtures of Freon and nitrogen gas was measured under a variety of conditions to determine the effect of

(*a*) Dilution of Freon by nitrogen.
(*b*) Change of pressure.
(*c*) Change of spark-gap length.

Results, which will be discussed below, were intermediate between those obtained in pure Freon and those obtained in pure nitrogen. This was the outcome that was to be anticipated. One very interesting relation, however, was discovered. It was found that a very small amount of Freon in nitrogen has a disproportionately large effect in raising the electric strength; this is discussed below.

Considerable difficulty was at first experienced in work with mixed gases, and results could not be repeated from time to time until an electric fan was used to insure thorough mixing of the gases within the test chamber. When the fan was used, however, the difficulty was entirely overcome, and sparking voltages were thereafter obtained with about the same degree of con-

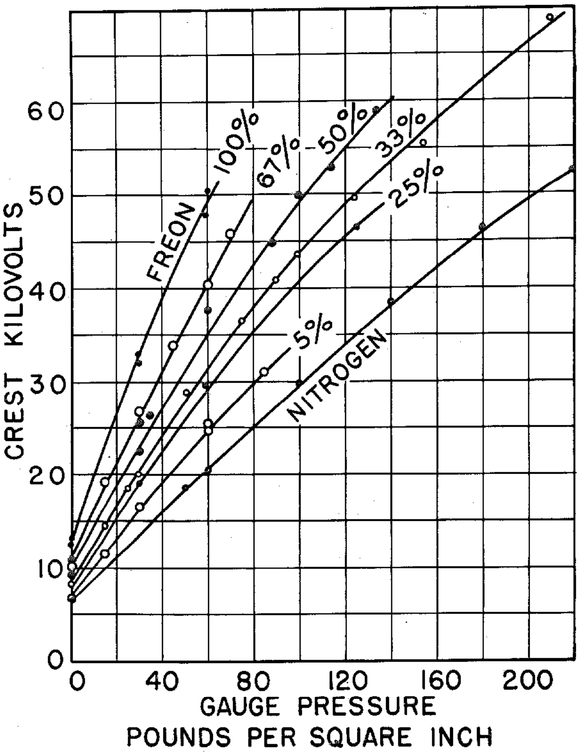

Fig. 4—Sparking Voltages in Mixtures of Freon and Nitrogen.
Spherical electrodes
Length of spark gap: 0.050 inch
Per cent of Freon by volume as noted on curves

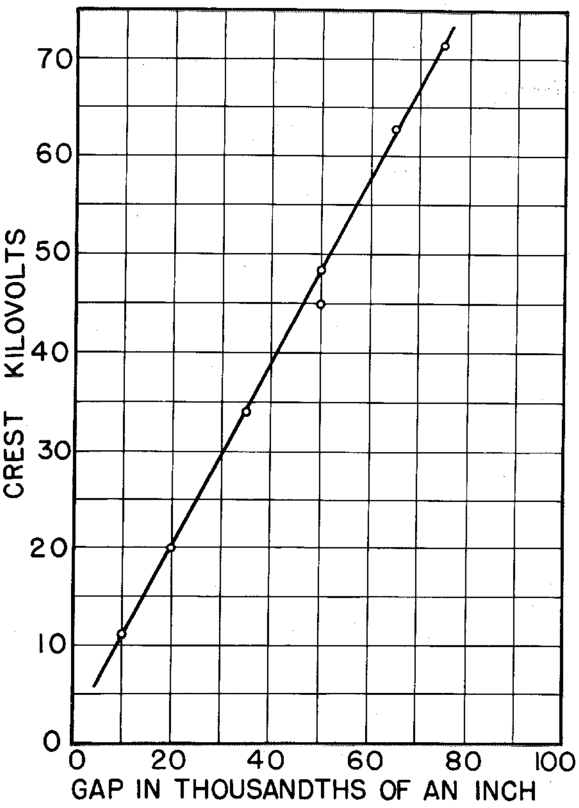

Fig. 5—Sparking Voltages in a Mixture of 50 per cent Freon and 50 per cent Nitrogen.

Spherical electrodes
Pressure seven atmospheres (90 pounds per square inch gauge)

sistency as in pure Freon; that is, individual readings of sparking voltage commonly varied two or three per cent above and below the average for a given condition, while a variation of as much as ten per cent was very unusual.

Mixtures of Freon and nitrogen that were given most attention contained 67% Freon, 50% Freon, 33% Freon, 25% Freon, and 5% Freon by volume. Most of the work was done with a spark-gap length of 50 mils (see Fig. 4). To give assurance that the normal relation between the sparking voltage and gap length exists in mixed gases, the gap length was varied from 10 to 75 mils in a mixture of 50% Freon and 50% nitrogen with the results shown in Fig. 5. As with pure gases, the voltage-distance relation is linear, and experimental data for this mixture of 50% Freon and 50% nitrogen can be represented by the formula

$$V = 132PS + 2.5 \text{ kv.}$$

(All experimental points lie within 10% of this expression.)

This suggests the possibility of finding a simple equation to represent data for all Freon-nitrogen mixtures at all pressures and spacings. For this purpose the data of Figs. 4 and 5 were replotted as Fig. 6. In this form it is evident that the relation between the amount of Freon present and the sparking voltage is linear when the concentration of Freon is greater than five per cent. When the concentration of Freon is less than five per cent a small amount of Freon produces a disproportionately large increase in the sparking voltage, as shown in detail in Fig. 6 at a pressure of three atmospheres. The linear relation shown in Fig. 6 leads to the following equation for sparking voltage in Freon-nitrogen mixtures in which the amount of Freon is greater than five per cent:

$$V = (88PS + 1.9)(1 + 1.08F),$$

where V is kilovolts, P is pressure in atmospheres, S is spacing in inches, and F is the fraction of Freon by volume, in the gas. (For pure Freon

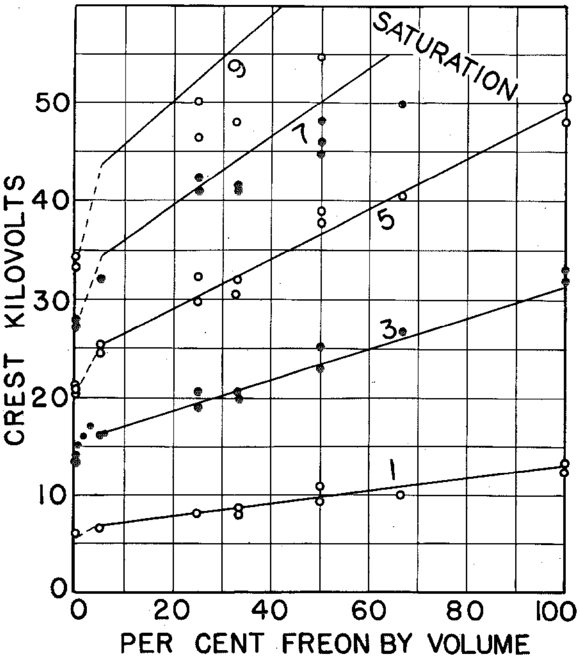

Fig. 6—Sparking Voltages in Mixtures of Freon and Nitrogen.

Spherical electrodes
Length of spark gap: 0.050 inch
Pressure in atmospheres as noted on curves
Points are experimental; lines are computed from $V = (88PS + 1.9)(1 + 1.08F)$ kv.

$F=1.0$; for half Freon, half nitrogen $F=0.5$; note that for pure nitrogen it is *not* correct to let $F=0$ as the formula does not apply for less than five per cent Freon.)

This equation is proposed with several reservations. As noted, it does not apply for very low concentrations of Freon. Another limitation is that the formula becomes inaccurate at high pressure. The agreement with experimental data is good for pressures up to five atmospheres. At pressures of seven atmospheres and more, the experimental sparking voltage is uniformly less than that predicted by the formula. There are two obvious explanations:

1. It is at about this same pressure that variation from a straight-line relationship becomes evident in pure air or nitrogen.
2. The discrepancies become more marked as the partial pressure of Freon in the gas under test approaches the vapor pressure of Freon.

A condition of saturation is approached when both pressure and concentration of Freon are high, corresponding to the upper right-hand corner of the chart. As the vapor pressure is approached the intermolecular forces become great and the Freon no longer approximates a perfect gas.

Finally, the formula given for mixtures of Freon and nitrogen is based on a limited amount of data. Since there are three independent variables in the equation, it would be an extremely lengthy procedure to determine the voltage for all possible combinations. The data at hand were obtained by recording slightly over a thousand individual sparking voltages, however, and appear adequate to give strong support to the above formula for pressures greater than one atmosphere, for spacings from a few mils to a few hundred mils, and for all concentrations of Freon greater than five per cent.

Some work was done with mixtures of air and Freon, but was discontinued when it was found that the products of electrical discharge were highly corrosive and tended to damage the apparatus. In particular, the spheres used as electrodes were tarnished after as few as three or four sparks and rapidly became coated with a grayish deposit. This corrosion, however, had very little effect on the electrical strength of the gap between the spheres. Indications are that the electric strength of air-Freon mixtures is similar to that of nitrogen-Freon mixtures.

Results With Pointed Electrodes

A short investigation was carried out to determine some of the salient characteristics of sparking in air, nitrogen, and Freon, between electrodes with sharp points.

Sparking in air between points was discussed at some length in a previous paper,[1] and present measurements agree, where comparable, with the results which were then obtained. Experimental procedure is difficult because the nature of the results depends to a large extent on the degree of sharpness of the points, particularly for short gaps. In general, however, as pressure is raised, the sparking voltage reaches a maximum; this maximum occurs at 8 to 12 atmospheres pressure. When pressure is further increased, the sparking voltage becomes less—sometimes very slightly less, sometimes by as much as 50%. The large decline of voltage with increasing pressure is obtained with very sharp points, while with blunt points the dip becomes less marked, and there may be no dip whatever if the points are either quite blunt or quite close together. The action is apparently dependent on whether or not corona precedes sparking; observation of corona has been made possible by the windows installed in the present test chamber.

Sparking in nitrogen between points was investigated for three lengths of gap. It was found that the sparking voltage in nitrogen is considerably lower than that in air for the lengths of gap studied. Curves of sparking voltage as a function of pressure are shown in Fig. 7. No direct comparison with the strength of air is possible because of the different shape of the curves, but it is seen from the figure that a 0.3-inch gap in air will withstand about as much voltage as a 0.5-inch gap in nitrogen. There is a decided difference in the shape of the curves; the curve for the 0.3-inch gap in nitrogen is practically flat for pressures above ten atmospheres, while the corresponding curve for air has a hump in the neighborhood of ten atmospheres pressure. When the gap is increased to 0.5 inches the curve for nitrogen is also humped, although to a lesser extent. Very short gaps (0.1-inch or less) fail to show any hump in either air or nitrogen, at least for points of ordinary sharpness. It may be mentioned that the sharpness of the points used was such that they would readily scratch the fingernail, and this sharpness was retained during sparking in nitrogen but sparking in compressed air tended to burn and blunt the points.

It is probable that difference between sparking between points in nitrogen and in air results from the high electron affinity of oxygen. Oxygen will allow the attachment of electrons to form negative ions; nitrogen will not.[6] This will greatly affect the mobility of space charge in the gas, and since sparking voltage between points is largely influenced by space charge, it is natural that nitrogen and air behave differently between points although they behave alike between spheres.

The voltage required to spark between points in Freon is considerably higher than for equal distances in air. Curves for sparking in Freon are shown in Fig. 7. Again a general comparison is practically impossible, but certain particular values may be compared in air and Freon.

The voltage required to spark 0.1 inch between points in Freon is for all pressures (from normal atmospheric pressure to the vapor pressure of Freon) greater than the voltage required to spark 0.3 inch in air or 0.5 inch in nitrogen. Over most of the pressure range the voltage required for the shorter gap in Freon is very considerably greater than for the longer gaps in air and nitrogen. It was found that a gap of 0.2 inch in Freon will support voltage comparable to published values for a gap of 30 to 50 millimeters (1.2 to 2.0 inches) in nitrogen.[7]

Since this paper was submitted, G. C. Nonken has published[10] sparking voltages for longer gaps in Freon. His curves for sparking between points (square rods) show the typical hump. A hump is just beginning to appear in the curve of Fig. 7 of this paper at the highest pressure obtainable in pure Freon, and with longer gaps it appears at lower pressure. At gap lengths of six and eight centimeters this maximum sparking voltage is at almost atmospheric pressure, and voltage declines as pressure is raised.

At atmospheric pressure comparison may be made between results obtained in Freon and the A.I.E.E. standard needle-gap sparking voltages for air, as shown in Table I.

TABLE I

Voltage Kv Crest	Length of Spark (Inches)	
	In Air (A.I.E.E. Standard)	In Freon (Experimental)
14.3	0.47	0.10
24.0	0.82	0.20

It will be seen that in general the increase of electric strength gained by the use of Freon is greater with pointed electrodes than with flat or spherical electrodes. The apparent reason is that with pointed electrodes, sparking is preceded by corona discharge, while there is no corona between spheres. The conclusion is that formation of corona is greatly impeded by Freon gas.

One of the more important and useful aspects of the behavior of Freon is the following. The maximum sparking voltage between points in Freon is greater than the sparking voltage of the same point-gap in air or nitrogen at any practical pressure of air or nitrogen. With a gap of 0.1 inch, for example, between points, Freon will withstand about 40 kilovolts at 50 to 60 pounds gauge pressure. According to data given by H. J. Ryan[8] a gap of the same length in air will not support more than 35 kilovolts even though the pressure is raised to 1,500 pounds. With longer gaps the advantage of Freon appears to be even greater.

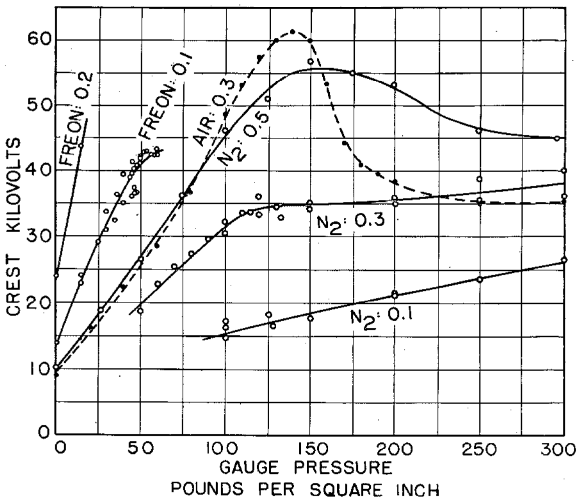

Fig. 7—Sparking Voltages in Nitrogen, Freon, and Air. Pointed electrodes
Gas tested, and spark-gap length in inches, as noted on curves

This advantage is peculiar to pointed electrodes. In nitrogen or air the sparking voltage between points reaches a maximum at a pressure of a few atmospheres and thereafter decreases with increasing pressure, or at the most, rises very gradually. When the gap in which sparking occurs is between smooth surfaces—between spherical electrodes, for example—the maximum strength of Freon may be equaled and exceeded in either air or nitrogen by sufficiently increasing the pressure but this is not possible if the spark occurs between points.

These facts appear to make Freon potentially more useful to prevent electric discharge from points or projections than to prevent sparking or breakdown in a substantially uniform electric field. On the other hand, it must be remembered that corona or other electric discharge must not ordinarily be allowed to take place in Freon, because the decomposition products are corrosive and somewhat poisonous.

Conclusions

1. The electric strength of nitrogen between smooth electrodes is almost exactly equal to that of air.

2. Sparking voltage between sharp points is higher in air than in nitrogen (see Fig. 7).

3. Freon gas (dichlorodifluoromethane) between smooth electrodes will withstand about two and a half times as much voltage as air or nitrogen at the same pressure, but it cannot be used at pressures above about 70 pounds per square inch, gauge, as that is its approximate vapor pressure at ordinary temperatures (see Figs. 2 and 3).

4. Mixtures of Freon and nitrogen are intermediate in characteristics between the two gases used alone (see Figs. 4 to 6). The most interesting characteristic of mixtures is the large increase in electric strength produced by a very small amount of Freon in nitrogen (see Fig. 6).

5. Freon gas between pointed electrodes increases the strength of the gap very greatly, the sparking voltage being found in some cases to be of the order of magnitude of four times that in nitrogen. The maximum sparking voltage in Freon is greater than the greatest sparking voltage that can be attained in air or nitrogen at any practicable pressure.

6. The greatest advantage in the utilization of Freon between smooth surfaces is where the pressure of gas that may be used is limited by mechanical considerations. For most purposes, nitrogen at 300 pounds per square inch pressure is superior to Freon, for it has as great an electric strength, is more consistent in behavior, and does not become corrosive in the presence of electric discharge. But if the gas pressure is limited by mechanical design to 150 pounds per square inch, or less, the possible use of Freon should be carefully considered.

7. The possibility of adding a small percentage of Freon to nitrogen, and thereby increasing its electric strength by 15 to 25% appears to be a practical consideration.

References

1. "The Electric Strength of Air at High Pressure," by H. H. Skilling, *A.I.E.E. Transactions*, Vol. 58, 1939, April section, pp. 161–5.
2. "The Electric Strength of Air at High Pressure—II," by H. H. Skilling and W. C. Brenner, *A.I.E.E. Transactions*, Vol. 60, 1941, March section, pp. 112–15.
3. "Dielectric Strength of Insulating Fluids," by E. E. Charlton and F. S. Cooper, *General Electric Review*, Vol. 40, September 1937, pp. 438–42.
4. "Some Studies on the Dielectric Strength of Insulating Fluids," by E. E. Charlton and F. S. Cooper, *The American Journal of Roentgenology and Radium Therapy*, Vol. 41, 1939, pp. 114–20.
5. "Thermodynamic Properties of Dichlorodifluoromethane (F-12)," by R. M. Buffington and W. K. Gilkey, Circular 12, American Society of Refrigerating Engineers, New York, 1931.
6. "On the Mechanism of Unimolecular Electron Capture," by F. Bloch and N. E. Bradbury, *Physical Review*, Vol. 48, 1935, pp. 689–95.
7. "The Breakdown of Compressed Nitrogen in a Non-uniform Electric Field," by I. Goldman and B. Wul, *Technical Physics* of the Union of Socialist Soviet Republics, Vol. 1, 1935, pp. 497–505.
8. "Air and Oil as Insulators," by H. J. Ryan, *A.I.E.E. Transactions*, Vol. 30, 1911, pp. 26–30.
9. "D-C Breakdown Strength of Air and of Freon in a Uniform Field at High Pressures," by J. G. Trump, F. J. Safford, and R. W. Cloud, *A.I.E.E. Transactions*, Vol. 60, 1941, March section, pp. 132–4.
10. "High-Pressure Gas as a Dielectric," by G. C. Nonken, *A.I.E.E. Transactions*, Vol. 60, 1941, December section, pp. 1017–20.

Wavelength Measurements of Decimetric, Centimetric and Millimetric Waves

By A. G. CLAVIER

Editor's Note:*—The present article was prepared and describes work done prior to September 1939. Due to war conditions, it was not published. It has been thought that it is still of interest, both technically and to establish more clearly the status of this particular type of work prior to the war period.*

Synopsis:*—In this article the measurement of waves shorter than one meter is considered and apparatus specially adapted to this purpose is described. Different types of available circuits are analyzed and compared, and problems of coupling to the source to be measured, as well as the necessary indicating apparatus, are outlined. A wavemeter with coaxial lines, suitable for the ready measurement of decimetric and centimetric wavelengths, is described. For the shortest wavelengths of the band under consideration, dielectric guides or interferometer methods used in the infra-red waveband may be applied.*

THE measurement of wavelengths below about one meter presents peculiar difficulties and necessitates the construction of specialized apparatus adapted to this purpose.

Up to the present it has not been possible conveniently to measure these very high frequencies by beating them with the harmonics of an oscillator stabilised, for example, by means of a piezo-electric crystal. With increasing fundamental frequencies, thinner crystals must be used and they consequently become very fragile. If, on the other hand, a much lower frequency is used, it is difficult to produce and amplify harmonics of a sufficiently high degree with vacuum tubes at present available. In this direction a limit is set by the influence of the internal connections and the time of transit of the electrons between the electrodes.[1]

Frequency meters of this kind, nevertheless, could be constructed for the lowest frequencies in the range under consideration.[2,3] The apparatus, however, would be cumbersome and would require delicate handling. In any case, wavemeters of lesser precision are needed for making measurements readily but with adequate accuracy, considering the present state of the art.

Such wavemeters can be obtained by using a high selectivity electric circuit tunable to the frequency to be measured. Association is required with (1) an element capable of being influenced by oscillation on the frequency to be determined, and (2) a detector element arranged to deflect a measuring instrument and to indicate that the tunable circuit of the wavemeter is in resonance.

In the region of decimetric waves, the longest in the field herein considered, it is still possible to construct an oscillating circuit of lumped electrical constants. The selectivity of such a circuit can easily be estimated by means of its magnification factor Q, derivable from low frequency technique. Fig. 1 shows a circuit consisting of an inductance L, a resistance R and a capacitance C in series. Between the terminals A and B an e.m.f. E of angular velocity ω is applied. For resonance, when $LC\omega^2=1$, the current is E/R. The voltage across the inductance

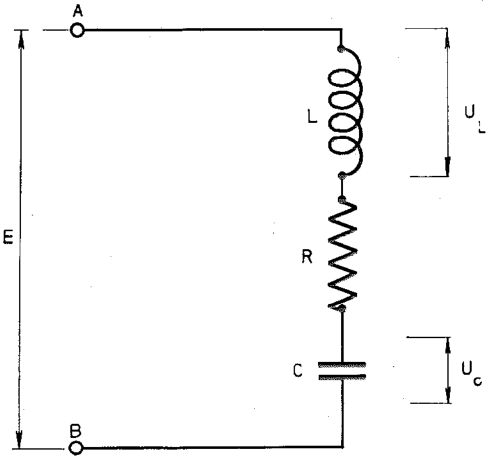

Fig. 1—Circuit for Wavelength Measurements.

and the capacitance are therefore:

$$U_L=\frac{E}{R}L\omega,\quad U_C=\frac{E}{R}\frac{1}{C\omega}.$$

These voltages are equal and their ratio to the e.m.f. applied to the terminals A, B of the circuit is the magnification factor Q:

$$Q=\frac{L\omega}{R}=\frac{1}{RC\omega}.$$

The magnification factor thus defined also characterizes the selectivity of the circuit. Actually, when not in resonance, the current in the circuit may be represented by the usual equations:

$$\frac{E}{R+j\left(\omega L-\dfrac{1}{\omega C}\right)}=\frac{E}{R}\cdot\frac{1}{1+j\dfrac{1}{R}\left(\omega L-\dfrac{1}{\omega C}\right)}.\qquad(1)$$

Let ω_0 be the resonance angular velocity for which $LC\omega_0^2=1$. If this velocity is changed by $\delta\omega_0$, where $\delta\omega_0/\omega_0\ll1$, the ratio of the current at angular velocity $(\omega_0+\delta\omega_0)$ to the resonance current is equal to

$$\frac{1}{1+j\dfrac{\omega_0L}{R}\cdot\dfrac{2\delta\omega_0}{\omega_0}}=\frac{1}{1+jQ\dfrac{2\delta\omega_0}{\omega_0}}.\qquad(2)$$

The sharpness of the resonance curve may be estimated by the difference $\delta\omega_0$ for which the current falls to a value $1/\sqrt{2}$ of the resonance current. Thus,

$$\frac{2\delta\omega_0}{\omega_0}=\frac{1}{Q}.\qquad(3)$$

An oscillating circuit therefore will be the more selective, the greater the value of Q. Consequently, for a given inductance L, it is necessary to reduce as much as possible the different resistances in the circuit. The preceding analysis, where it is assumed that $\delta\omega_0/\omega_0$ remains $\ll1$, does not apply except where the resistance is small compared to the reactance $L\omega$.

The different resistances in the oscillating circuit are:

1. High frequency resistance of the wire constituting the inductance;
2. Resistance due to losses in the part of the condenser dielectric subjected to the high frequency field;
3. Resistances due to radiation of the loop constituting the inductance and radiation of the condensers.

An examination of these different resistances shows that, for wavelengths up to 30 cm, it would be difficult for the magnification factor to exceed a few hundred. Rohde, in the wavelength range of 60–30 cm, gives as an example a factor Q of approximately 100 for a circuit consisting of a copper wire 4 mm in diameter, forming a single spiral 25 mm in diameter. This spiral is associated with a condenser, the plates of which are copper rings 8 mm in diameter; their separation is adjustable by means of micrometer screws. Such a wavemeter cannot be easily coupled to the source to be measured, or to a detector suitable for use at fairly high frequencies. From this point of view the best results are obtainable with diodes constructed so that the transit time of the electrons should not be troublesome.[1]

Obviously, circuits possessing greater magnification factors and adaptability are needed.

Butterworth[5] made an investigation of the values of Q that might be expected for inductances of predetermined geometric form. His computations, however, do not allow for losses due to radiation and apply to lower frequencies than those under consideration.

To eliminate radiation, toroidal windings may be used. For a winding of this type, with circular cross-section and with turns touching (Fig. 2), the inductance and resistance are given by

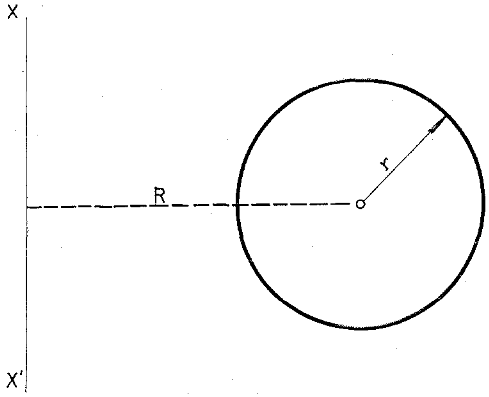

Fig. 2—Toroidal Inductance.

$$L=4\pi N^2[R-\sqrt{R^2-r^2}]\times10^{-9}\text{ henries,}\qquad(4)$$

$$R_\Omega = 2\pi\sqrt{\rho}N^2 \cdot \frac{r}{R} \cdot \frac{1}{\sqrt{1-\left(\frac{r}{R}\right)^2}} \cdot \sqrt{f} \times 10^{-9}\text{ ohms,} \quad (5)$$

where N is the number of turns and ρ is the resistivity in electromagnetic units (about 1700 for copper).

Expressing the frequency in megacycles per second (F):

$$Q = \frac{\omega L}{R_\Omega} = 303\sqrt{F} \cdot \phi(r, R). \quad (6)$$

The function ϕ, when $(R+r)=b$ is kept constant, has a maximum for $r/R=0.707$. For this value

$$Q_{\text{opt}} = 52b\sqrt{F} = 89R\sqrt{F}. \quad (7)$$

By adding the resonance condition,

$$L_{\mu H}C_{\mu F} = \frac{25200}{F^2}, \quad (8)$$

to this equation the curves of Fig. 3 result for the case of a single spiral, which is the most favourable condition for very high frequencies. These curves show that it is theoretically possible to obtain magnification factor values very much higher than those given by the circuits previously considered. In practice, however, it is difficult to attain the very low values of capacitance necessary for tuning, and it is even more difficult to vary this capacitance. Finally, difficulties of coupling to the source to be measured and procuring a suitable measuring detector remain very great. This type of circuit is consequently more suitable for very high frequency oscillators than for wavemeters and has been thus utilized in various ways by Kolster,[6] more recently by Hollmann,[7] and especially by Hansen[8, 9] in his researches on velocity modulation oscillators at Stanford University.

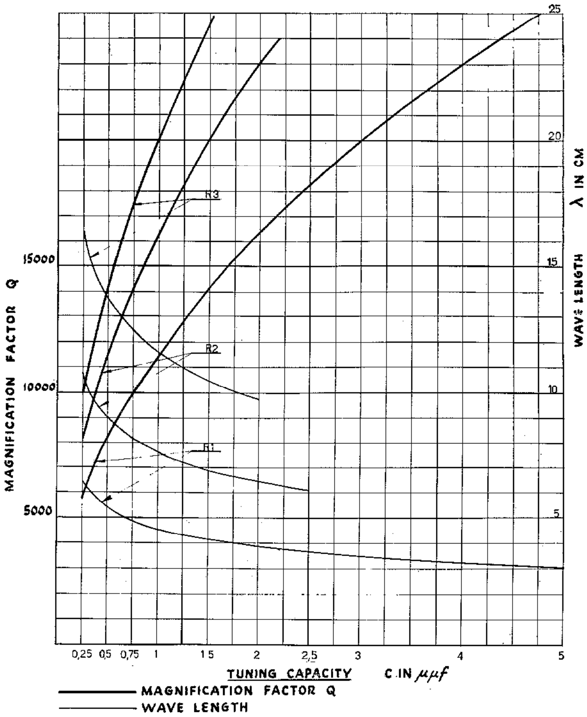

Fig. 3—Resonance Conditions of Tuned Toroidal Windings.

Circuits with Distributed Constants

The foregoing considerations and the necessity of finding an easy method of calibration in terms of wavelength have led to the use of circuits with distributed constants and, in particular,

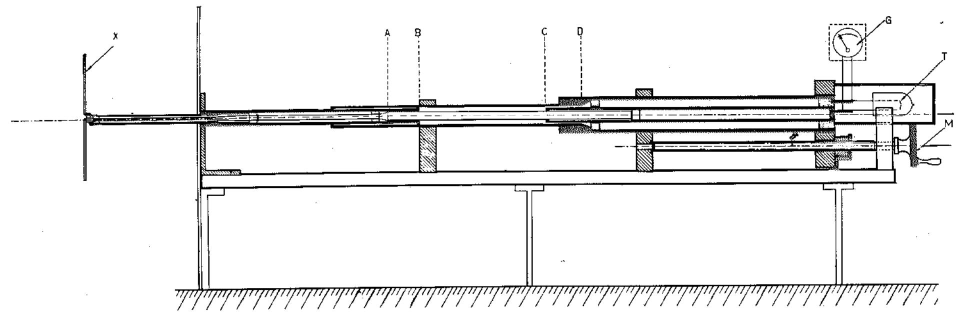

Fig. 4—Wavemeter with Coaxial Lines.

transmission lines. In the first instance, transmission lines made up of two parallel wires were considered, the systems being known technically as Lecher wires. In a system of this kind with separation between the wires small compared with the wavelength, radiation can as a first approximation be ignored and Kirchhoff's laws applied by assigning line constants R, L, C to the line. For very high frequencies, leakance between wires may be ignored.

For such a circuit it is possible to define a coefficient Q which plays the same part, so far as selectivity is concerned, as the magnification factor in circuits with lumped constants. Considering a short-circuited line of length l, calculation gives the input impedance as

$$Z=Z_0 \tanh\left(\alpha l+j\frac{2\pi l}{\lambda}\right); \tag{9}$$

Z_0 is the characteristic impedance of the line, equal to $\sqrt{L/C}$, and α is the attenuation constant equal to $R/2Z_0$.

The impedance is a maximum for the quarter-wave line; hence

$$Z_{\lambda/4}=\frac{Z_0}{\tanh \alpha l}. \tag{10}$$

If the attenuation is low, the approximation

$$Z_{\lambda/4}=\frac{Z_0}{\alpha l} \tag{11}$$

is obtained.

This expression is not valid unless αl is sufficiently small compared with 1; for an infinite attenuation $\tanh \alpha l$ tends towards 1, and $Z_{\lambda/4}$ towards Z_0.

The frequency f_0 corresponds to a wavelength λ_0 for which the length of the line is a quarter wavelength; changing by δf_0 such that $\delta f_0/f_0$ is small compared with 1, the impedance becomes

$$Z=\frac{Z_0}{\alpha l}\cdot\frac{1}{\left(1+j\frac{\pi}{\alpha\lambda_0}\cdot\frac{2\delta f_0}{f_0}\right)}. \tag{12}$$

The modulus of the impedance then drops from 1 to $1/\sqrt{2}$ for a frequency difference δf_0 such that

$$\frac{2\delta f_0}{f_0}=\frac{\alpha\lambda_0}{\pi}. \tag{13}$$

The quantity $\pi/\alpha\lambda_0$ defines the selectivity of the system and corresponds to the magnification factor.

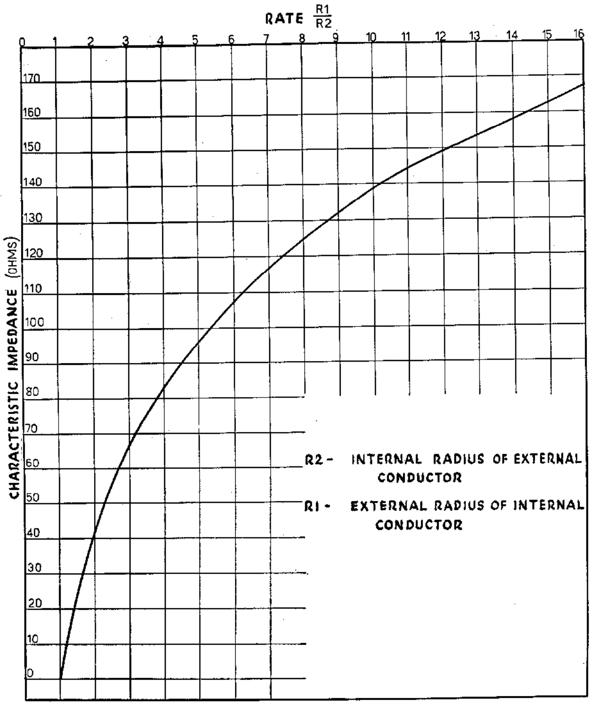

Fig. 5.

This expression becomes clearer if the expression for a circuit with lumped constants is written

$$Q=\frac{\omega_0 L}{R}=\frac{\pi}{(R/2L)T_0}=\frac{\pi}{(1/\theta)T_0}; \tag{14}$$

T_0 is the resonance period and θ the time constant of the circuit.

Conversely, replacing α by its expression as a function of the constants of the line,

$$Q=\frac{\pi}{\alpha\lambda_0}=\frac{\omega_0 L}{R}, \tag{15}$$

where L and R are constants per unit of length.

Transmission lines with parallel wires can therefore be used as circuits for the measurement of wavelengths and are especially suitable for decimetric wavelengths. The resonance positions are repeated periodically along the line and their separation gives the wavelength to be measured. Such lines, with variations have been used by numerous experimenters (see, for example, Hund[10] at the Bureau of Standards, and, in France, the theses of Mercier and Laville).

In these measurements the distance between two consecutive resonances is not exactly equal to half a wavelength in air. The phase velocity along the wires is $1/\sqrt{LC}$ and L varies with frequency. As a first approximation it is possible to take (Stéfan)

$$L=L_\infty+\frac{R_\omega}{\omega}; \tag{16}$$

L_∞ is the inductance per unit length corresponding to a purely surface current distribution at infinite frequency. As R_ω is small compared with $L_\infty\omega$,

$$v=c\left(1-\frac{R}{2L_\infty\omega}\right)=c\left(1-\frac{1}{2Q}\right) \tag{17}$$

approximately, where c is the velocity in air. The error is very small for the frequencies considered in this article.

Lecher-wire wavemeters are in current use for the measurement of decimetric waves. They, however, have the following disadvantages: the higher the frequency the more the line radiates; moreover, it is difficult to localize the excitation at one point of the line, thus making the application of the previous theory doubtful; finally, it is not easy to eliminate effects due to surrounding objects and movements of the operator. It is consequently preferable to use *coaxial lines.* A wavemeter of this type, described below, was designed in 1931 at the Laboratories L.M.T. by the author and one of his colleagues, René Darbord.[11]

Coaxial-line Wavemeter

The wavemeter illustrated in Fig. 4 comprises essentially a test line BC of length adjustable by means of a micrometer movement M; this line is connected to the antenna X and to the thermocouple T through quarter-wave lines AB and CD. The lines in front of A towards the antenna and behind D towards the thermocouple present impedances at A and D which, in order to simplify this description, are assumed to be purely resistive lines (ρ and ρ') adjusted, for example, to a halfwave-length.

Further, let it be assumed that the characteristic impedances of the quarter-wave lines are equal (Z_1) and that Z_2 is the characteristic impedance of the measuring line. Then, in order to obtain sufficient sensitivity, it will be found that the resistances introduced by the coupling with the antenna and the thermojunction are large compared with the resistance of the measuring line, which may be neglected to a first approximation. Under these conditions, if E is the e.m.f. induced in the antenna by the source to be measured, the current in the thermocouple becomes,

$$I_\alpha=E\frac{Z_1^2Z_2}{\sqrt{(A^2\cos^2\beta l+B^2\sin^2\beta l)}}, \tag{18}$$

where

$\beta=2\pi/\lambda$,

$l=$ length of the measurement line,

$A=Z_1^2Z_2(\rho+\rho')$,

$B=Z_1^4+\rho\rho' Z_2^2$.

The variation of I_α with l depends on $(B-A)$ which may be written

$$(Z_1^2-\rho Z_2)(Z_1^2-\rho' Z_2). \tag{19}$$

Several different cases may arise. In the wavemeter under consideration, Z_2 is made very much greater than Z_1^2/ρ and Z_1^2/ρ'. The current I_α is a maximum when the measuring line is a quarter wave long. It falls to $1/\sqrt{2}$ of its maximum value for

$$\sin\beta l=\pm\frac{A}{\sqrt{(B^2-A^2)}}; \tag{20}$$

approximately,

$$l=\frac{\lambda}{2}\pm\frac{\lambda}{2\pi}\,\frac{A}{\sqrt{(B^2-A^2)}}. \tag{21}$$

Predetermination of the accuracy of the measurement is thus possible. It is advisable to make Z_2 as large as possible, and Z_1 as small as possible.

The quantities Z_1 and Z_2 depend only on the ratio of the internal radius of the external conductor to the external radius of the internal conductor of the coaxial lines. The impedance obtained may be read from the curve of Fig. 5.

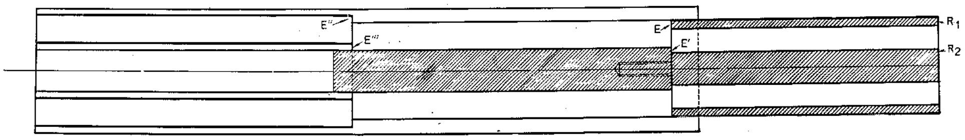

Fig. 6—Adjustable Line with Constant Characteristic Impedance.

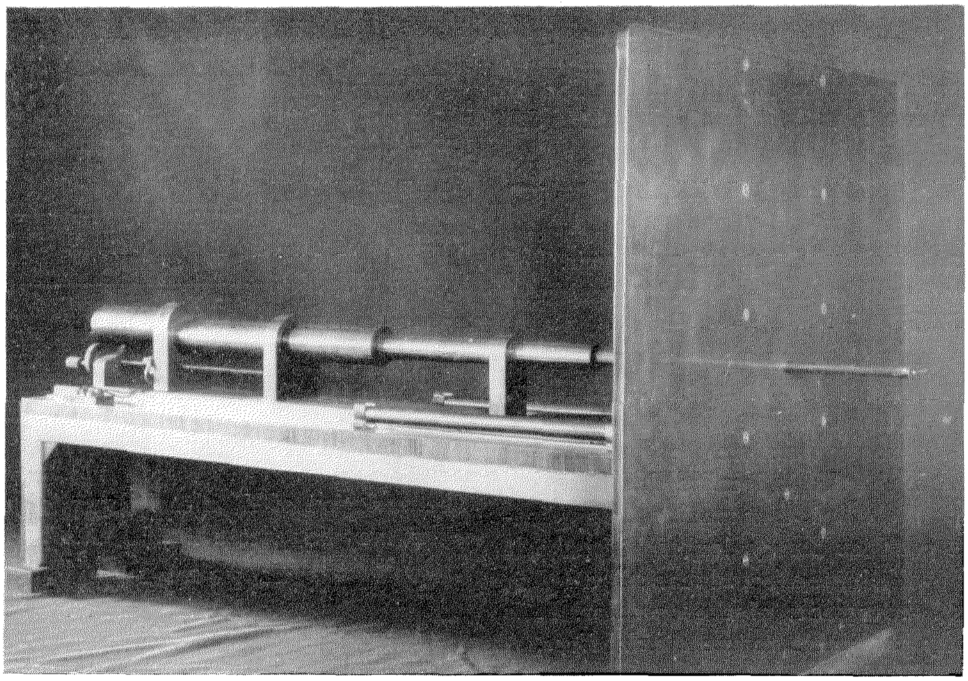

Fig. 7—Complete Wavemeter with Coaxial Lines.

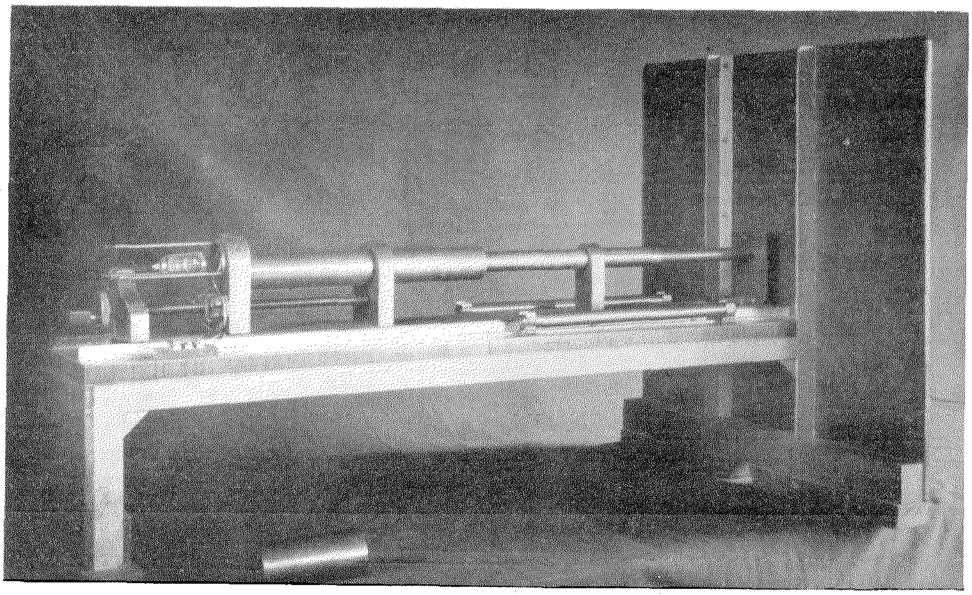

Fig. 8—Rear View of Wavemeter with Coaxial Lines.

In the models constructed it is possible to measure the wavelength to an accuracy of one part in 2000. This measurement, just as for Lecher wires, is subject to an error due to the phase velocity along the line not being equal to the propagation velocity in free space. This error is, however, very small at the high frequencies herein considered.

The above analysis strictly applies only under conditions of precise adjustment of all the lines which constitute the wavemeter. But the quarter-wave lines remain effective over a fairly wide wavelength band; the wavemeter operates correctly, for example, from 12–24 cm when the quarter-wave sections are adjusted for 17 cm.

To obtain a measuring line the characteristic impedance of which does not vary regardless of the length used, it is preferable to use the device pictured in Fig. 6. The shaded parts are movable en bloc. The characteristic impedance is constant along the line provided that the steps E, E', E'' and E''' are such that

$$\frac{R_1}{R_2}=\frac{E}{E'}=\frac{E''}{E'''}.$$

Figs. 7 and 8 are photographic reproductions of the coaxial-line wavemeter above described. They show the ease of coupling with the source to be measured and suggest the absence of interference effects due to movements of the operator when he stands behind the reflector associated with the antenna.

Coaxial-line wavemeters may be used for the measurement of wavelength up to the centimeter-waveband. For wavelengths of a few centimeters, however, the influence of the transverse dimensions of the coaxial line causes trouble and coupling problems arise. Dielectric guides therefore become necessary.

Dielectric Guides for the Measurement of Centimetric Wavelengths

The simplest dielectric guides consist merely of a metallic pipe without an inside conductor. Theory and experiment show that electromagnetic waves may be propagated through them provided that the wavelength in air is below a certain limit which is of the order of the diameter of the guide. Reference may be made to previous articles published in connection with this subject for justification of the exposition which follows (see for example, references 12, 13, 14, 15, 16 and 17).

This type of circuit does not readily lend itself to the determination of line constants, but the coefficient which plays the part of the factor Q

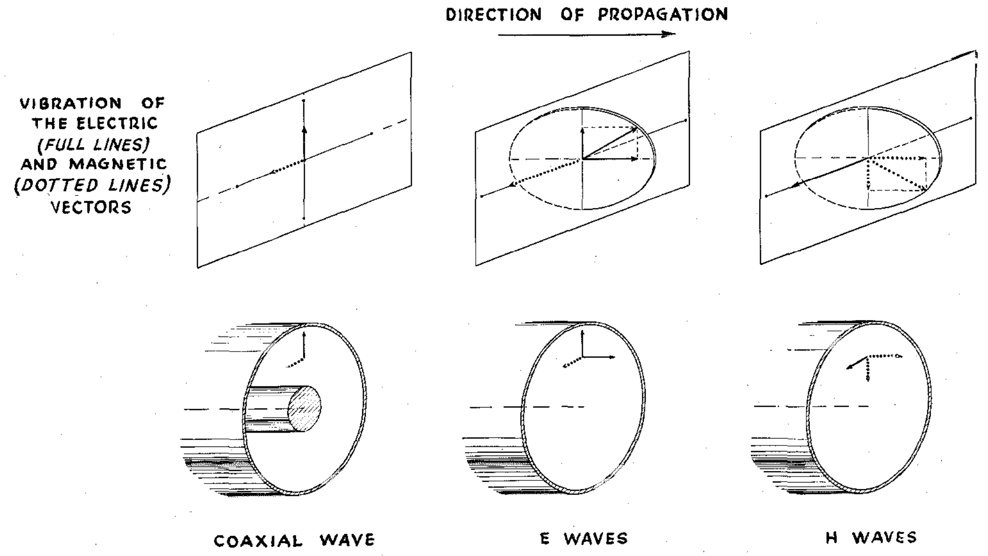
DIRECTION OF PROPAGATION
VIBRATION OF THE ELECTRIC (FULL LINES) AND MAGNETIC (DOTTED LINES) VECTORS
COAXIAL WAVE
E WAVES
H WAVES

Fig. 9.

may be defined in terms of energy. For a circuit with lumped constants

$$Q=\frac{\omega L}{R}=2\pi\cdot\frac{LI^2}{RI^2}\cdot\frac{1}{T}, \tag{22}$$

where I is the rms current and T the oscillation period. Except for 2π, this is the ratio of the average stored electromagnetic energy to the amount of energy dissipated as heat during a given period.

Applying this definition to the case of a cylindrical dielectric guide, let $\overline{W}_{\text{tot}}$ be the stored electromagnetic energy per unit of length averaged over a period and $\overline{Q}_c$ the quantity of energy lost as heat per unit of length and per unit of time (losses in the dielectric, air generally, are negligible). Then

$$Q=\frac{2\pi}{T}\cdot\frac{\overline{W}_{\text{tot}}}{\overline{Q}_c}. \tag{23}$$

But the coefficient of attenuation is related to $\overline{Q}_c$ and to the mean power $\overline{W}_z$ delivered through a cross-section;[17] hence,

$$\alpha=\frac{\overline{Q}_c}{2\overline{W}_z}$$

and, consequently,

$$Q=\frac{\pi}{\alpha T}\cdot\frac{\overline{W}_{\text{tot}}}{\overline{W}_z}. \tag{24}$$

$T\overline{W}_z$ is the energy which passes through a cross-section per period. This energy occupies a guide length λ_g such that

$$T\overline{W}_z=\lambda_g\overline{W}_{\text{tot}};$$

hence

$$Q=\frac{\pi}{\alpha\lambda_g}. \tag{25}$$

Calculation shows, as might be expected, that λ_g is the wavelength corresponding to the group velocity, V_g, determining the speed of transmission of energy. In dielectric guides V_g and the phase velocity V_p are such that

$$V_g V_p=v^2, \tag{26}$$

where v is the velocity of propagation in free space. In coaxial lines, to the same approximation, $V_g=V_p=v$, which again gives the expression used above.

The constant $Q=\pi/\alpha\lambda_g$ may easily be computed for dielectric guides. It is, however, necessary to recognize *the different wave structures* which may be propagated and which each give different values of α and λ_g.

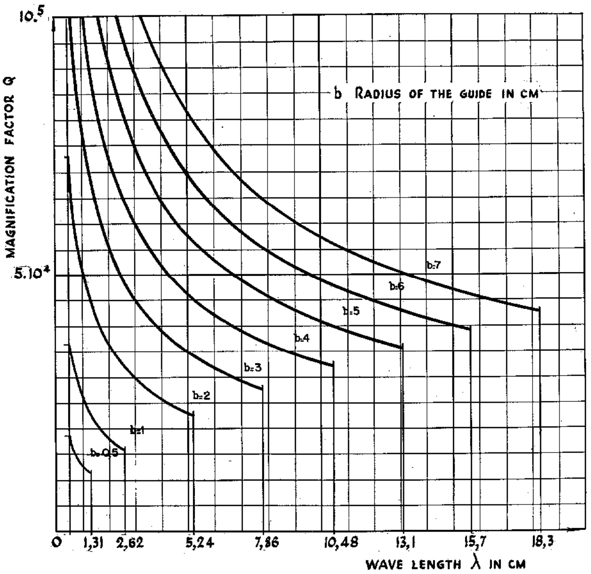

Fig. 10.

The principal structures are classified as E waves and H waves, characterized by the directions of the electric and magnetic vectors. This classification is shown diagrammatically in Fig. 9 where, for purposes of comparison, the directions of the vectors in the lossless coaxial line are given.

For fundamental wave structures[16, 17] calculation gives:

$$E_0 \text{ Wave} \quad Q_{E0}=\frac{\pi}{2}\cdot\frac{b\sqrt{f}}{\alpha_0 v} \tag{27}$$

$$H_0 \text{ Wave} \quad Q_{H0}=\frac{\pi}{2}\cdot\frac{b\sqrt{f}}{\alpha_0 v}\cdot\frac{f^2}{f_c^2} \tag{28}$$

$$H_1 \text{ Wave} \quad Q_{H1}=\frac{\pi}{2}\cdot\frac{b\sqrt{f}}{\alpha_0 v}\cdot\frac{1}{0.44+(f_c^2/f^2)}. \tag{29}$$

In these expressions b is the radius of the guide, f_c the cut-off frequency, v the velocity of propagation in free space and α_0 a coefficient which depends on the materials employed. If μ_1 and μ_2 are the permeabilities of the dielectric and of the conductor, ϵ_1 the dielectric constant of the dielectric, and σ_2 the conductivity of the conductor,

$$\alpha_0=\frac{1}{4}\cdot\sqrt{\frac{\mu_2\epsilon_1}{\sigma_2\mu_1}}. \tag{30}$$

Put in the same form, the coefficient of the coaxial cable becomes

$$Q_c=\frac{\pi}{2}\cdot\frac{b\sqrt{f}}{\alpha_0 v}\cdot\frac{2}{\left(1+\frac{b}{a}\right)\Big/\left(\text{logh}\ \frac{b}{a}\right)},\qquad(31)$$

a maximum occurring when the ratio b/a of the radii is equal to 3.6 (minimum attenuation). This coefficient takes account only of the copper losses; in the E_0 case, it is lower in the ratio of 1 to 1.8.

The expression $\pi/2\cdot b\sqrt{f}/\alpha_0 v$ may also be put in the form $\mu_1/\mu_2\cdot b/\delta$, where δ is the skin thickness at the frequency used;[8]

$$\delta=\frac{1}{\sqrt{(2\pi\sigma_2\mu_2\omega)}}.\qquad(32)$$

It can be shown that the above expressions are applicable at the cut-off frequency. This is the case with which Hansen deals. The tuning of the circuit then no longer depends on the length of the guide sections but only on the radius. Propagation in the strict sense along the axis does not really take place; the circuit may be likened to one with lumped constants. The coefficient Q may therefore be given the form

$$Q_{E_0}=\frac{\pi}{\left(\frac{Rl}{2\mu_1 l}\right)T},\qquad(33)$$

where l is the axial length, and the circuit may be considered as having an inductance per unit length equal to μ_1.

Hansen[8] allows for losses in the terminal walls, which multiply the above factor Q by $1/(1+b/l)$.*

The order of magnitude of the factor Q_{E_0} to which theory points is shown by the curves of Fig. 10.

To measure wavelengths with dielectric guides, it is necessary to transform the wavelength measured along the guide into the wavelength in air. Experiment indicates that it is possible, in the present state of the art and with transmitter frequency stability available, to rely on the theoretical relationships established between these wavelengths. This relationship is given by the curves of Fig. 11 for the principal wave structures which require consideration.[18] It will be appreciated that it is advisable to work fairly closely to the cut-off wavelength since in this region a relatively small variation in the frequency causes a considerable variation in the wavelength along the axis of the guide.

Measurements of wavelength have been made below a centimeter with the equipment illus-

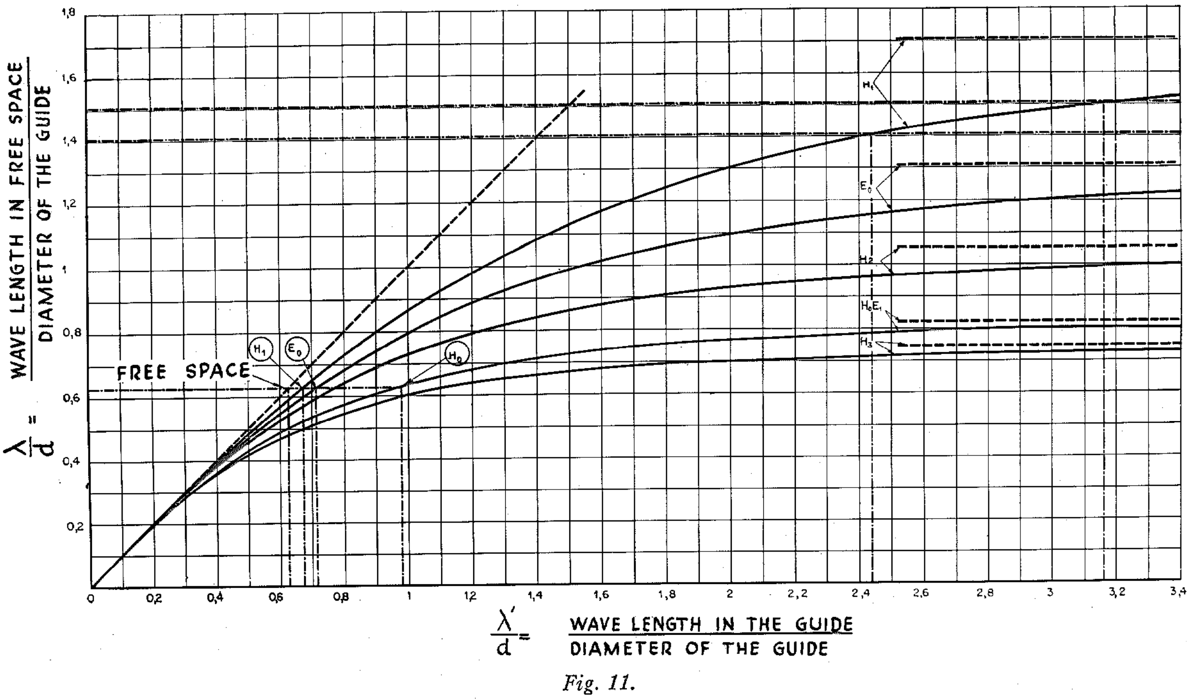

Fig. 11.

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* It will be noted on reading Hansen's article [8] that the thickness of the skin which he deals with is equal to $1/\sqrt{2}$ of the quantity δ used in the present treatise.

trated in Fig. 12. The wavelength of a magnetron especially constructed for wavelengths of this order required determination. The magnetron sent an H_1 wave into a guide of 0.5 cm radius. A crystal detector was coupled to the guide and connected to the milliammeter visible in the figure. At the end of the guide a movable piston, which had very good high frequency contacts with the wall of the guide, was displaced by a micrometer lead. Accuracy was increased by taking measurements at a certain number of half wavelengths.

Other methods of measurement have been utilized. In particular, the quasioptical properties of these oscillations suggest the adaptation of interferometers and gratings. Thus, as might be expected, there is a tendency towards the technique of measurement used at the long end of the infra-red spectrum.

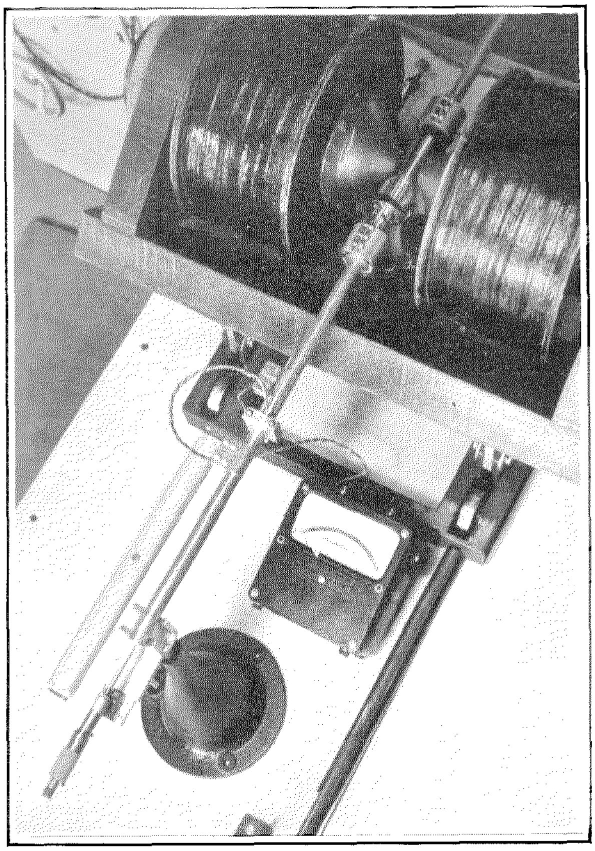

Fig. 12—Measuring Device Using a Dielectric Guide.

Bibliography

1. "The Influence of Transit Time of Electrons in Vacuum Tubes," by A. G. Clavier, *B.S.F.E.*, Jan., 1939, p. 79.
2. "Crystal Control of Decimeter Waves," by H. Straubel, *H.F.T. and El. Ak.*, May, 1936, p. 152.
3. "Some Problems of Hyperfrequency Technique," by A. G. Clavier and E. Rostas, *El. Com.*, Vol. 16, No. 3, 1938.
4. "Ein Wellenmesser für Dezimeter-Wellen," by L. Rohde, *E.N.T.*, Vol. 13, No. 1, p. 13, 1936.
5. "Designing Low-Loss Receiving Coils," by S. Butterworth, *Wireless World*, Vol. 19, 1926: Dec. 8, p. 754; Dec. 15, p. 811.
6. "Generation and Utilization of Ultra-Short Waves in Radio Communication," by F. A. Kolster, *Proc. I.R.E.*, Vol. 22, 1934, p. 1335.
7. "Der Kugelsender," by H. E. Hollmann, *H.F.T. and El. Ak.*, Oct., 1937, p. 109.
8. "A Type of Electrical Resonator," by W. W. Hansen, *Jnl. of Applied Physics*, Oct., 1938, p. 654.
9. "On Resonators Suitable for Klystrom Oscillators," by W. W. Hansen and R. D. Richtmyer, *Jnl. of Applied Physics*, Mar., 1939, p. 189.
10. "Theory of Determination of Ultra Radio Frequencies by Standing Waves on Wires," by A. Hund, Bureau of Standards, Scientific Paper No. 491, 1924.
11. "Reflecteurs et Lignes de Transmission pour Ondes Ultracourtes," by R. Darbord, *Onde Elec.*, Feb., 1932, p. 53.
12. "Hyperfrequency Wave Guides—Mathematical Theory," by J. R. Carson, S. P. Mead and S. A. Schelkunoff, *B.S.T.J.*, April, 1936, p. 310.
13. "Hyperfrequency Wave Guides—General Considerations and Experimental Results," by G. C. Southworth, *B.S.T.J.*, April, 1936, p. 284.
14. "Propagation d'Ondes Electromagnétiques dans un Tuyau," by L. Brillouin, *R.G.E.*, Vol. 40, No. 8, Aug. 22, 1936, p. 227.
15. "Theoretical Relationships of Dielectric Guides (Cylindrical) and Coaxial Cables," by A. G. Clavier, *B.S.F.E.*, Vol. 8, No. 88, Apr., 1938; *El. Com.*, Vol. 17, No. 3, 1939.
16. "Theoretical Study of Dielectric Cables," by L. Brillouin, *El. Com.*, Vol. 16, No. 4, 1938.
17. "Supplementary Study on the Coefficients of Attenuation in Dielectric Guides (Cylindrical) and Coaxial Cables," by A. G. Clavier and V. Altovsky, *B.S.F.E.*, Vol. 8, No. 93, Sept., 1938.
18. "Experimental Researches on the Propagation of Electromagnetic Waves in Dielectric (Cylindrical) Guides," by A. G. Clavier and V. Altovsky, *R.G.E.*, Vol. 45, May 27 and June 3, 1939; *El. Com.*, Vol. 18, No. 1, 1939.
19. "Grating Theory and Study of the Magnetostatic Oscillator Frequency," by C. E. Cleeton, *Physics*, June, 1935, p. 207.
20. "On a Method of Measuring Frequency by Means of the Cathode Oscillograph," by Th. Vogel, *Reports of the Assoc. of Scientists of Rumania*, Oct. 29, 1937.

Some Simplified Methods of Determining the Optical Characteristics of Electron Lenses*

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Editor's Note. *Novel methods of obtaining optical characteristics of electron lenses were developed by the authors in the course of a general research on electron optics. The work has been carried on by the Electrical Engineering Department of Stanford University under the sponsorship of the International Telephone and Telegraph Corporation.*

Summary

Some new methods of calculating lens characteristics are proposed which are relatively simpler and more accurate than those previously suggested. The first is an extension of Salinger's method of joined circular segments applied to paraxial rays in fields with a rotational symmetry. This requires as information only the axial potential and derivatives thereof. This method is the computational equivalent of the original graphical method. A second method makes use of the action function which is approximated from the potential function. Electron paths are taken as normal to the lines of constant action. A third method replaces the convergent and divergent parts of the usual lens with equivalent thin lenses and then calculates the focal lengths by means of combination formulas applied to the two thin lenses. All calculating methods are, however, sufficiently long in application and indeterminate in accuracy that experimental methods of finding lens characteristics are preferred.

A new experimental method makes use of a demountable vacuum tube. Lens characteristics are determined from angular magnifications measured from the shadows cast by object screens illuminated by a point source of electrons. No moving screens are required nor is it necessary to generate rays parallel to the axis. By observing magnifications for all voltage ratios for two positions of the object screen enough data are available to determine the four cardinal focal distances for all voltage ratios. The results are considered more accurate and cover a greater range of voltage ratios than those reported by previous investigators. A graphical method has been developed for determining the spherical-aberration characteristics of the lens from the curvature of the object-screen images observed on the fluorescent screen.

Results are presented in a new and simplified form in addition to the standard form showing the variation of focal distances with voltage ratio. The new form gives associated object and image distances and corresponding magnification for any voltage ratio. The relation between the four useful variables is thus given on one chart for each lens. In effect this new form is a graphical presentation of the complete solution of the lens equation which shows clearly the relation between the four associated variables and gives quantitative results which can be applied directly. The new form reveals a number of properties of lens strength and magnification which have not been previously recognized.

I. Methods of Calculating Electron Paths

A. PREVIOUS METHODS

A NUMBER of methods for calculating the characteristics of electron lenses from the potential field have been proposed. All of these calculate the principal rays of the lens, that is, the rays entering the lens parallel to the axis from the right and from the left, and then determine the location of the focal points and principal planes from these rays. When the four cardinal values of the lens, that is, the location of the two focal points and the two principal planes are known as a function of the voltage ratio, then the operation of the lens is completely determined.

The method of Klemperer and Wright[1] is the trigonometric ray-tracing method of physical optics applied to electrostatic lenses. The electrostatic field is broken up into a succession of thin

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* Paper presented before the Summer Convention of the I.R.E., Detroit, Michigan, June 24, 1941. Reprinted from *Proceedings of the I.R.E.*, March, 1942.

[1] O. Klemperer and W. D. Wright, "Investigations of Electron Lenses," *Proc. Phys. Soc.*, March, 1939, **51**, part II, pp. 296–317.

lenses having a constant ratio of equivalent index of refraction for adjacent lenses. Formulas are given for calculating the effect of every refraction at a lens surface upon the angle of a ray and the point at which it crosses the axis. Lens surfaces are assumed to be spherical and their radius of curvature must be determined either graphically or from the axial potential. The method requires a large number of equivalent thin lenses, at least twenty for an accurate determination, and the results converge slowly as the number of segments taken is increased.

From purely mechanical considerations Maloff and Epstein[2] have proposed several methods based upon a step-by-step solution of the differential equation of the paraxial electron. The methods give the electron path as an exponential function of the axial distance in any increment and join the paths in successive increments both in magnitude and slope. The methods are capable of good accuracy but the computations are lengthy. Information necessary for calculation is the axial potential and its derivatives.

Another approximate method based upon the differential equation of the paraxial electron has been proposed by Gans.[3] The axial potential is replaced by a number of straight-line segments which approximate it closely and the differential equation is then solved for the successive regions in which the potential is linear and the gradient is constant. At each boundary between segments there is a jump in the slope of the electron path because of the infinite value of the second derivative of potential at the junction of the straight-line segments. The final path as determined by this method consists of a number of curved segments of path connected together, giving a path which is continuous but which has discontinuities in slope at the corners of the segmented approximation to the axial distribution of potential. Such a path cannot represent accurately the true nature of the path within the lens but it can be used to obtain relations between initial and final values with considerable accuracy. The method is relatively easy to apply and gives fair accuracy for as few as six segments in the approximate axial potential curve.

B. Method of Joined Circular Segments

A new method which is the equivalent in simplicity and accuracy of any of the methods described above is based upon an extension of the general method of Salinger.[4] By considering the electron path to be a section of a circle at any point, it follows from equating the centrifugal force of the motion to the centripetal force of the field that the instantaneous radius of curvature is given by $R=2E/\overline{\nabla_n E})$ where E is the potential at the point in question and $\overline{\nabla_n E}$ is the component of the gradient of the potential normal to the instantaneous direction of motion. This is a relation which holds for all fields and permits a graphical construction of an electron path to be made by joining segments of circles tangentially.

For application to the case of paraxial electrons in an electron gun a graphical method is not feasible because the radii of curvature are so long that they cannot readily be drawn. However, it is possible to make use of the well-known series expansion for potential along the axis to obtain some simple relations which will give a step-by-step location of the electron as it moves through the field. For electrons close to the axis and making a small angle with it the normal component of the gradient is

$$\overline{\nabla_n E}=\sqrt{(r^2E_0'')^2+(E_0'\theta)^2}, \tag{1}$$

in which the subscript zero indicates axial potential, the primes indicate derivatives in the axial direction, θ is the angle which the ray makes with the axis, and r is the radial distance from the axis to the electron path. If the radius of curvature R is determined from the potential E and the normal gradient as given in (1), and the electron be assumed to be swung through a circular arc of angle x such that the displacement Δs is about 1/40 of the distance through the lens, then the axial displacement Δz equals the displacement Δs to within 0.1%. Thus

$$\Delta z=Rx \tag{2}$$

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[2] I. G. Maloff and D. W. Epstein, "Electron Optics in Television," McGraw-Hill Book Company, New York, N. Y., 1938, pp. 81–89.

[3] R. Gans, "Electron Paths in Electron Optics," *Zeit. für Tech. Phys.*, February, 1937, **18**, pp. 41–48.

[4] H. Salinger, "Tracing Electron Paths in Electric Fields," *Electronics*, October, 1937, **10**, pp. 50–54.

and the radial displacement is given by

$$\Delta r = Rx\left(\theta + \frac{x}{2}\right). \tag{3}$$

Initial and final values of r and θ for any increment are obviously given by

$$r_f = r_i - \Delta r, \tag{4}$$

$$\theta_f = \theta_i - x, \tag{5}$$

in which the subscripts f and i represent final and initial values.

By means of the above formulas the path through a lens may readily be calculated. The method is quite accurate because the path is made up of short segments of arcs of circles which join tangentially.

C. ACTION FUNCTION METHOD OF CALCULATING ELECTRON PATHS

This method is based upon the principle that electrons will move in paths which are normal to surfaces of constant action where the action a is defined as the integral of the product of the square root of potential and distance

$$a = \int \sqrt{E\,ds} \tag{6}$$

and is given in general by

$$(\nabla a)^2 = E, \tag{7}$$

which may be written as

$$\left(\frac{\partial a}{\partial r}\right)^2 + \left(\frac{\partial a}{\partial z}\right)^2 = E \tag{8}$$

in cylindrical co-ordinates.

The method given here approximates the action function from the known potential and then determines the electron paths through the action field. This is done by writing action as an even-powered series in r

$$a = a_0 + a_2 r^2 + a_4 r^4 + \cdots, \tag{9}$$

where the a's are functions of axial distance. Taking the gradient of this, squaring, and then equating term for term to the expression for potential gives

$$a_0'^2 = E_0 \tag{10}$$

and

$$4a_2^2 + 2a_0'a_2' = -E_0''/4 \tag{11}$$

as relations determining the first two coefficients.

The last differential equation cannot readily be solved exactly, but a solution over a small interval in which the coefficients may be considered to remain constant gives

$$a_{2R} = \frac{a_{2L} - \dfrac{E_0''z}{8\sqrt{E_0}}}{1 + \dfrac{2a_{2L}z}{\sqrt{E_0}}}, \tag{12}$$

where a_{2R} is the value of a_2 at the right of the interval and a_{2L} is the value at the left. By means of the above expression it is possible to calculate the value of a_2 as a function of z. When this is known, enough information is available to determine the path of an electron entering the lens parallel to the axis.

At any point in the lens the slope of the electron path M is given by the ratio of the r to the z component of the gradient of the action function. For electrons close to the axis this is

$$M = \frac{2a_2 r}{\sqrt{E_0}}, \tag{13}$$

from which

$$\Delta r = (2a_2 r/\sqrt{E_0})\Delta z, \tag{14}$$

so that

$$\ln_e \frac{r_2}{r_1} = 2\int_{z_1}^{z_2} \frac{a_2}{\sqrt{E_0}} dz, \tag{15}$$

in which r_2 and r_1 are final and initial radial distances, respectively, and z_2 and z_1 are the final and initial axial distances between which the calculations are made. The distances z_1 and z_2 are the points at the ends of the gun field at which the derivatives of potential are inconsiderable. This integral tells at what distance r_2 from the axis an electron will emerge from the lens if it enters at a distance r_1 from the axis.

The above integral is readily evaluated numerically. When the initial and final radial distances as given by the above integral are known and the initial and final slopes are also known the focal distance and location of the principal plane are easily determined. The principal plane is located by the intersection of the straight-line-path portions through the initial and final points drawn with the initial and final slopes, respectively. The focal distance is the reciprocal of the final slope multiplied by the final radial distance.

The method outlined above requires, as data from which to work, only the axial distribution of potential. The advantages of the method are that the numerical processes involved are relatively simple to apply and that the actual numerical work involved is less than that involved in any of the other methods tested. Essentially there is only one step-by-step formula to apply and the results of this operation are integrated through the lens structure. The only disadvantage of the method is that it is not valid in cases in which the electron crosses the axis within the lens structure. This is not a serious limitation because most of the practical lenses focus well beyond the last electrode.

D. METHOD OF EQUIVALENT THIN LENSES

The usual electron lens has a convergent behavior on the low-potential side and a divergent behavior on the high-potential side, the net lens behavior being convergent. The behavior is convergent when the second derivative of the axial potential is positive and divergent when the second derivative is negative. It is reasonable, therefore, to consider that the lens is made up of two thin lenses, a convergent lens followed by a divergent lens.[5] If the strength and location of these lenses are known the cardinal points of the equivalent thick lens may be determined.

The focal lengths of the convergent lens as shown in Fig. 1 are given by

$$\frac{1}{F}=\int_{z_1}^{z_m}\frac{E''}{2\sqrt{2E}}dz \tag{16}$$

and

$$f_1=F\sqrt{2E_1}, \tag{17}$$

$$f_2=-f_1\sqrt{E_m/E_1}, \tag{18}$$

where F is a focal term from which the focal lengths are derived, E_1 is the lowest potential on the lens axis, E_m is the potential at the point at which the second derivative assumes a value of zero, changing sign. The integration of (16) is carried over the region in which the second derivative is positive.

Similarly the focal distances for the divergent component of the lens are given by

$$\frac{1}{F'}=\int_{z_m}^{z_2}\frac{E''dz}{2\sqrt{2E}} \tag{19}$$

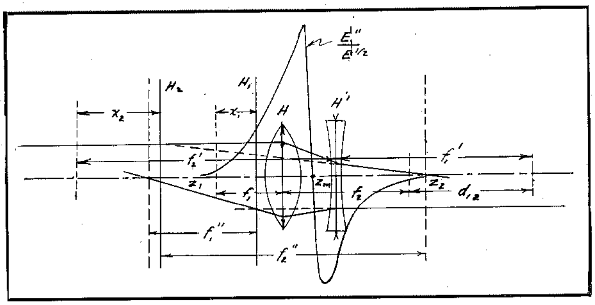

Fig. 1—Thin-lens Equivalent of a Thick Lens: Nomenclature.

and

$$f_1'=F'\sqrt{2E_m}, \tag{20}$$

$$f_2'=-f_1'\sqrt{E_2/E_m}, \tag{21}$$

where E_2 is the highest value of potential reached on the axis on passing through the lens.

When the focal lengths of the convergent and divergent components of the lens are known the focal characteristics of the entire lens are readily determined, this being a simple problem in the combination of lenses. When the distance between the second focal point of the convergent component and the first focal point of the divergent component is d_{12} then the focal lengths of the entire lens are[6]

$$f_1''=-f_1f_2/d_{12}, \tag{22}$$

$$f_2''=f_1'f_2'/d_{12}. \tag{23}$$

The location of the first principal plane measured from the first focal point of the convergent component is

$$x_1=f_1f_2/d_{12}+f_1'' \tag{24}$$

and the location of the second principal plane as measured from the second focal point of the divergent component of the lens is

$$x_2=f_1'f_2'/d_{12}+f_2''. \tag{25}$$

The method is extremely rapid in application. Some uncertainty exists as to the exact location of the thin lens components. The location of the lens components is best taken as being at the center of the area represented by the integrals of (16) and (19), as shown in Fig. 1.

All of the methods referred to above are subject to some error which is difficult to determine except by more detailed and extensive calculations. In general it may be said that although the methods are satisfactory, experimental methods are preferable, and usually more dependable.

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[5] L. M. Myers, "Electron Optics," D. Van Nostrand Company, New York, N. Y., 1939, p. 131.

[6] S. Rosin and O. H. Clark, "Combinations of Optical Systems," *Jour. Opt. Soc. Amer.*, March, 1941, **31**, pp. 198–201.

II. Experimental Method

A. METHOD OF DETERMINING FOCUSING CHARACTERISTICS

The experimental method used in determining the lens characteristics is based upon observed magnifications of measuring grids placed before and after the lens structure.

A grid of closely spaced parallel wires (for measurement purposes only and not for control of the beams) is placed in the fore part of the lens. This grid casts a shadow upon a fluorescent screen following the lens. In order to avoid the need of a tube having parts which can be moved relative to one another while in a vacuum, another measuring grid is used between the end of the gun and the fluorescent screen. This arrangement is shown schematically in Fig. 2 in which the measuring grid in the fore part of the lens is indicated by a horizontal row of dots. With this arrangement of measuring grids, it is necessary to make observations on the magnifications of two grids, as the voltage ratio of the main lens electrodes is varied, for each of two distances of the lens from a point source of electrons. Hence two complete runs must be made to obtain the data from which the complete lens characteristics can be measured.

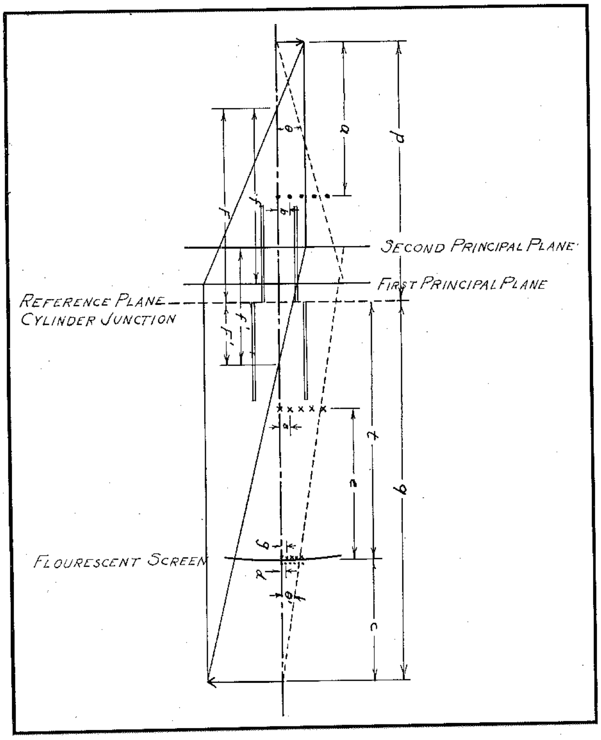

Fig. 2—Experimental Determination of Lens Characteristics.

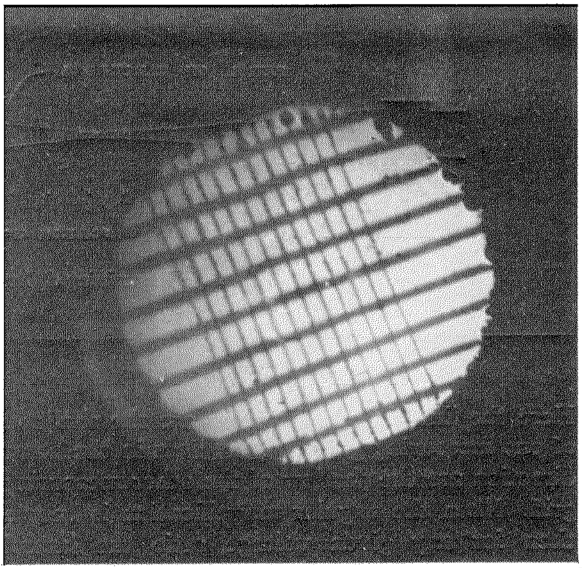

Fig. 3—Shadows of Measuring Grids on Fluorescent Screen.

The details of the mathematical relations involved can be seen from Fig. 2. The cathode-lens structure gave the effect of a point source of electrons at a known point near the cathode. The location of this point and the constancy of its position under varying conditions of lens voltage ratio were determined by placing two measuring grids in the fore part of the lens and observing the ratio of their magnifications. The constancy of the ratio of magnifications indicated that the location of the point source changed very little with lens voltage ratio and also over the normal range of control-grid voltages used. The location of the point source was very nearly at the control-grid aperture. When these facts were once determined from a test run it was no longer necessary to use two measuring grids in the fore part of the lens.

With the point source of electrons available the following general method is applied: The angular magnification of the bundle of rays is determined from screen patterns obtained on the fluorescent screen, such as that shown in Fig. 3.

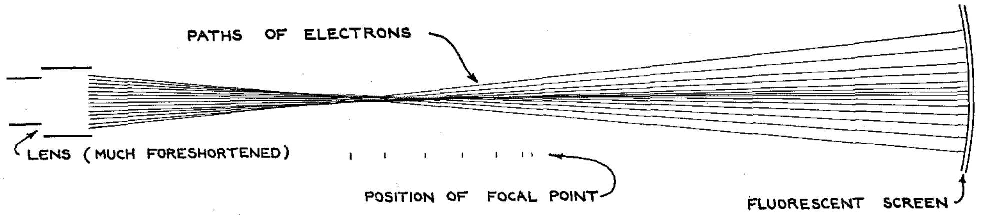

Fig. 4—Graphical Method of Determining Spherical Aberration: 1.5 to 1 Cylinder Lens, $E_2/E_1=4.5$.

Here the lines in one direction are the shadows of one measuring grid and the lines in the other direction are the shadow of the other measuring grid. When the angular magnification is known then for any given voltage ratio the lateral magnification can be determined from Lagrange's law, which states that the product of the internal magnification and the angular magnification is equal to the square root of the ratio of the final and initial potentials.[7] Image distances at each of the two object distances used are given for various voltage ratios from magnifications of the second grid alone. The object distances are known from physical measurements on the gun assembly. When lateral magnification, object distance, and image distance are known as a function of voltage ratio for two different values of the object distance then the cardinal quantities f, f', F, and F' of the lens may be calculated readily.

The method by which this calculation is made will be briefly indicated. Object and image distances can be expressed in terms of the lateral magnification and focal distances as

$$p=-f/m+F, \tag{26}$$

$$q=-mf'+F'. \tag{27}$$

These two equations involve the four quantities f, f', F, and F' as unknowns. In order to determine them it is necessary to know two sets of associated values of p, q, and m for the same voltage ratio. When subscripts 1 and 2 are used to indicate values of p, q, and m for two different values of p at a given voltage ratio, then there may be obtained from the above relations the following expressions for the cardinal focal distances

$$f=\frac{p_1-p_2}{\dfrac{1}{m_1}-\dfrac{1}{m_2}}, \tag{28}$$

$$f'=\frac{q_1-q_2}{m_1-m_2}, \tag{29}$$

$$F=\frac{p_1m_1-p_2m_2}{m_1-m_2}, \tag{30}$$

$$F'=\left(\frac{q_1}{m_1}-\frac{q_2}{m_2}\right)\bigg/\left(\frac{1}{m_1}-\frac{1}{m_2}\right). \tag{31}$$

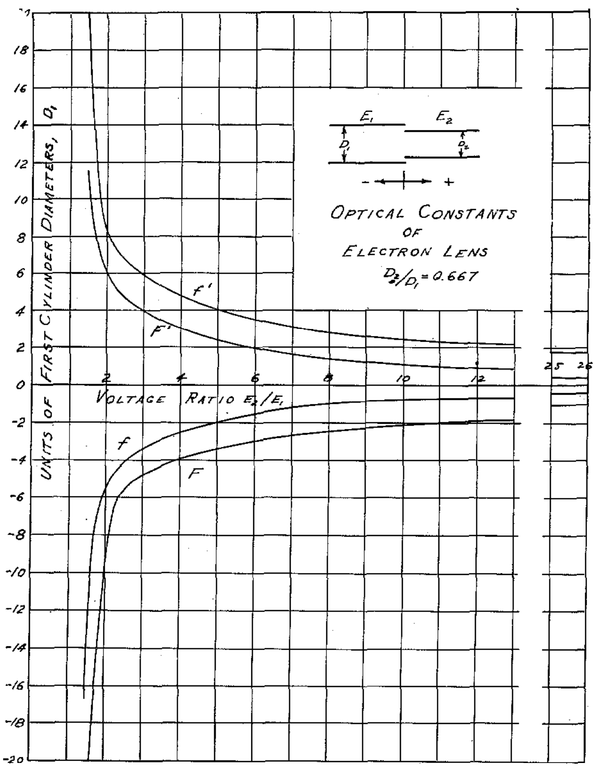

Fig. 5—Optical Constants at a Two-diameter Cylinder Lens, $D_2/D_1=0.667$.

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[7] O. Klemperer, "Electron Optics," Cambridge University Press, New York, N. Y., 1939, p. 12.

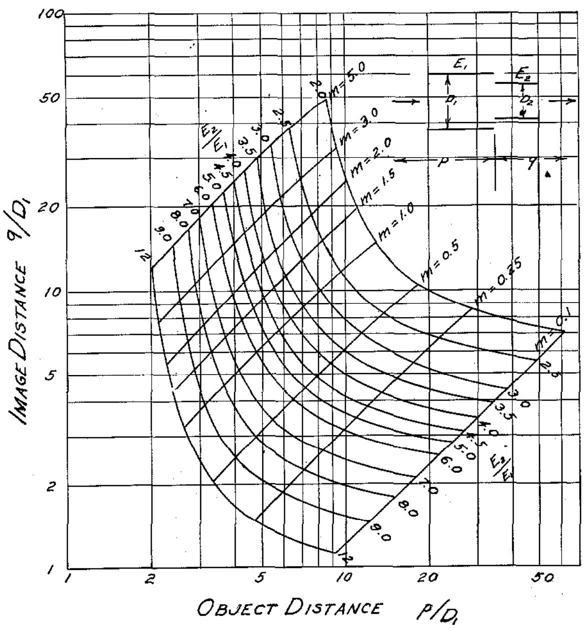

Fig. 6—Object-image—Distance Curves of a Two-diameter Cylinder Lens, $D_2/D_1=0.667$.

Up to this point the relations are the same as those used by Maloff and Epstein.[2] It is now only necessary to show how the lateral magnification may be deduced from the screen patterns to complete the collection of necessary relations. Referring to Fig. 2 it is seen that the angular magnification is given by

$$m_a=\theta'/\theta. \tag{32}$$

For small angles such as are encountered in the gun the angular magnification in terms of the dimensions is given very closely by

$$\theta'/\theta=ad/bc, \tag{33}$$

in which c is the distance beyond the fluorescent screen to the point at which the ray would focus. This distance is determined from the spacings of the grid images as follows:

For focus beyond fluorescent screen

$$c=\frac{e}{1-\frac{s}{g}}. \tag{34}$$

For focus between second measuring grid (crosses) and fluorescent screen

$$-c=\frac{e}{1+\frac{s}{g}}. \tag{35}$$

When the angular magnification is known, then the lateral magnification may be calculated from Lagrange's law as previously indicated.

With the above relations the cardinal quantities are readily calculated. In practice this is most easily done by plotting curves of the various quantities involved against voltage ratio because the same voltage-ratio observations may not have been taken on one run as on the other. There is a small hole in each curve at the point where the beam focus is at the fluorescent screen because the image becomes so small here that it is not possible to measure the spacings of the wires on the images. However, there is no trouble in drawing smooth and continuous curves through these holes if the data are taken with care. It is convenient to plot curves of reciprocal magnification rather than of magnification because the latter becomes infinite when the focus is on the fluorescent screen, whereas the reciprocal magnification is continuous through zero at this point.

B. Determination of Aberration Characteristics

Of all the types of aberrations encountered in electrostatic lenses, the most serious is spherical

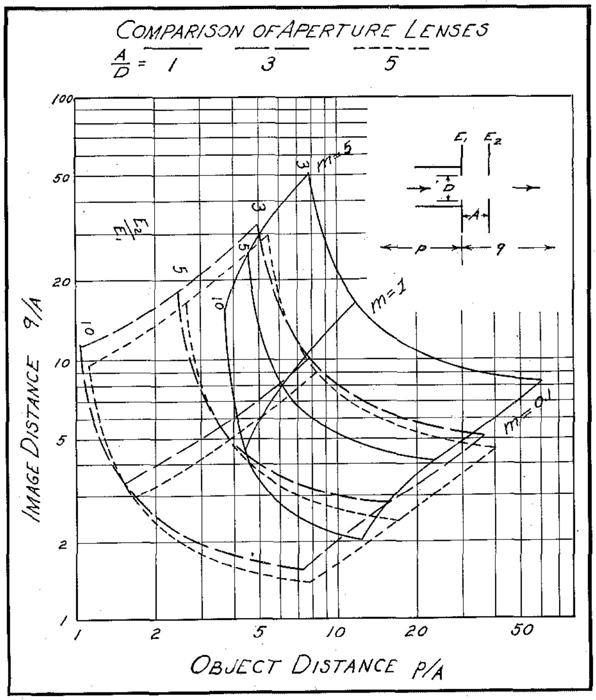

Fig. 7—Comparison of Aperture Lenses.

aberration. This is always present to some degree and is very difficult to reduce and nearly impossible to eliminate completely.

The screen patterns from which the focusing characteristics were obtained can also be used to determine the spherical aberration. The intersections of the grid-wire images tell how far from the axis any ray, starting off of the axis, will fall in the image. With this information it is possible to determine the spherical aberration by a graphical method. A ray diagram such as that shown in Fig. 4 can be drawn connecting points on the image with corresponding points of emergence at the lens. From this diagram it is possible to determine the variation in the focal point with the original radial distance of the rays. It is also possible to determine the minimum spot for any lens aperture.

III. Results

This paper is concerned primarily with methods and there will be given here only samples of the results as obtained by the methods described.

A. OPTICAL CONSTANTS

The focusing characteristics of the lenses tested may be presented in what has become a conventional form. In this form the focal distances and the distances from a reference point in the lens to the focal points are plotted as a function of the voltage ratio. Such a representation is given in Fig. 5 in which the reference point is the cylinder junction. It is seen that the characteristics are readily obtained for an extremely wide range of voltage ratios, roughly 25 to 1.5, or about three times any previously reported.

B. OBJECT-IMAGE DISTANCE CURVES

The focal characteristics were also presented in a new form which is believed to have many advantages over the conventional representation. From (26) and (27) it is seen that at any given voltage ratio the object and image distances are parametric with magnification in terms of the focal distances. Since the focal distances themselves are quantities which are used in determining the answer to any lens problem but

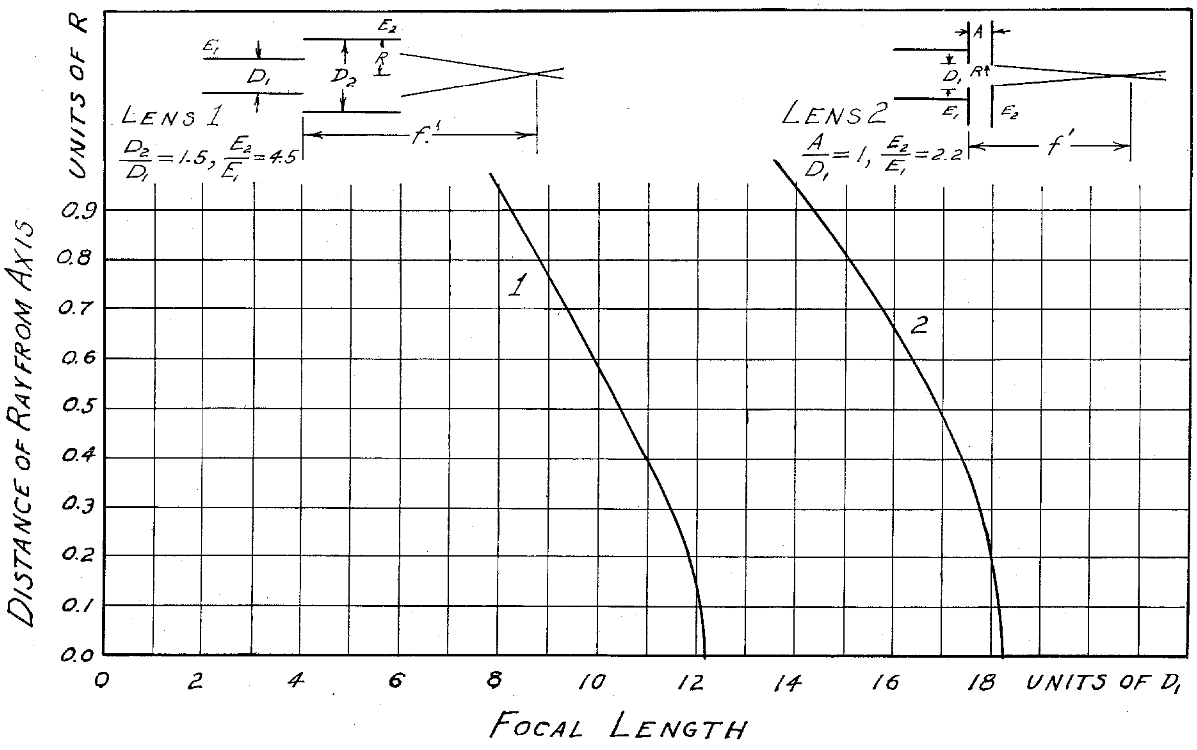

Fig. 8—Spherical Aberration of Lenses: Variation of Focal Distance with Aperture.

which do not appear in the answer it seems logical to seek a representation in which these quantities do not appear. Such a representation is shown in Fig. 6. This representation will be referred to as the object-image—distance curves of the lens. The curves give immediately the image distance corresponding to any object distance at a given voltage ratio and show also the corresponding magnification. Essentially this is a graphical representation of the solution of all possible problems associated with the lens.

The object-image—distance curves have several important merits. They give immediately quantitative relations between the controllable variables. They make possible a design procedure which is direct and does not depend upon any trial-and-error calculations. They show very clearly the effect of changes in voltage and physical structure. They reveal some universal lens properties which may not have been noted previously. They make possible a quick and comprehensive comparison of the characteristics of different lenses or of lenses of the same type with different dimensions. Such a comparison is shown in Fig. 7 which shows the effect of changing the ratio of aperture diameter to aperture spacing in an aperture lens. In this figure, object distance and image distance are measured from the first aperture, D is the aperture diameter, and A is the axial distance between apertures.

C. ABERRATION CHARACTERISTICS

Some typical aberration curves as determined graphically from the screen patterns are shown in Fig. 8. These show the decrease in focal distance as the ray separation from the axis is increased. Such curves are about the same for all lenses. These curves are nearly universal in that the reduction in focal distance is approximately a percentage function of the focal distance itself. A sample curve showing the spread of spot produced by aberration is shown in Fig. 9. This is also nearly a universal curve.

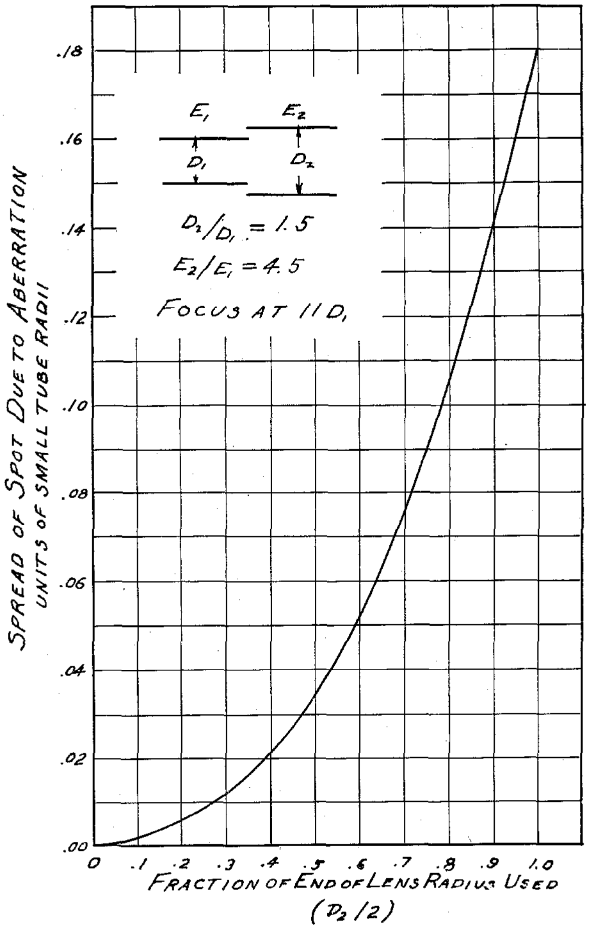

Fig. 9—Aberration Curve: Variation of Minimum Spot Size with Aperture.

IV. Conclusions

The methods proposed here are improvements on previously proposed methods from the standpoint of simplicity, ease of execution, and accuracy of results. The new representation of lens characteristics tells the whole story of the lens at a glance. The experimental method permits simultaneous determination of focal characteristics and aberration properties.

Telephone Statistics of the World[1]

Countries	Date of Statistics	Number of Telephones			Telephones per 100 Population
		Government Systems	Private Companies	Total	
NORTH AMERICA:					
United States#	Jan. 1, 1941	—	21,928,182	21,928,182	16.56
Canada	"	222,580	1,238,458	1,461,038	12.78
Central America	"	15,249	20,360	35,609	0.41
Mexico	"	3,000*	175,726	178,726	0.89
West Indies—					
Cuba	"	891	67,592	68,483	1.57
Puerto Rico	"	531	17,456	17,987	0.95
Other Places in the West Indies	"	11,464	21,168	32,632	0.39
Other Places in North America	"	100	20,452	20,552	5.19
Total	"	253,815	23,489,394	23,743,209	12.66
SOUTH AMERICA:					
Argentina	Jan. 1, 1941	—	460,857	460,857	3.46
Bolivia	"	—	2,621	2,621	0.08
Brazil	"	1,291	289,619	290,910	0.65
Chile	"	—	90,943	90,943	1.81
Colombia	"	9,000*	33,233	42,233	0.46
Ecuador*	"	4,200	3,400	7,600	0.26
Paraguay	"	—	3,800	3,800	0.39
Perú	"	—	35,151	35,151	0.52
Uruguay	Jan. 1, 1939	34,810	11,846	46,656	2.20
Venezuela	Jan. 1, 1941	760	31,096	31,856	0.88
Other Places in South America	"	3,398	—	3,398	0.60
Total (Estimated as of Jan. 1, 1941)		60,000	965,000	1,025,000	1.11
EUROPE:					
Belgium	Jan. 1, 1940	428,752	—	428,752	5.11
Bulgaria	"	31,225	—	31,225	0.48
Denmark	"	17,813	441,944	459,757	11.95
Eire	Mar. 31, 1941	46,726	—	46,726	1.56
Finland	Jan. 1, 1940	8,837	177,736†	186,573	4.81
France	"	1,622,680	—	1,622,680	3.86
Germany (incl. Austria and Sudetenland)	June 30, 1939	4,226,504	—	4,226,504	5.28
Great Britain and No. Ireland	Mar. 31, 1941	3,348,000	—	3,348,000	7.00
Greece	Jan. 1, 1940	5,967	48,437	54,404	0.76
Hungary	"	178,325	790	179,115	1.76
Italy	Jan. 1, 1941	—	685,815	685,815	1.58
Netherlands	Jan. 1, 1940	461,424	—	461,424	5.23
Norway	June 30, 1939	153,000*	97,000*	250,000	8.52
Portugal	Jan. 1, 1941	21,000*	54,803	75,803	0.98
Roumania	"	92,107	—	92,107	0.51
Russia¶	Jan. 1, 1939	1,272,500	—	1,272,500	0.75
Spain	Jan. 1, 1941	—	336,448	336,448	1.31
Sweden	"	906,917	1,736	908,653	14.26
Switzerland	"	474,038	—	474,038	11.23
Yugoslavia	Jan. 1, 1940	72,000*	—	72,000	0.45
Other Places in Europe*	Jan. 1, 1941	550,000	130,000	680,000	1.20
Total (Estimated as of Jan. 1, 1941)		13,920,000	1,980,000	15,900,000	2.75
ASIA:					
British India	Mar. 31, 1939	31,878	51,500	83,378	0.02
China*	Jan. 1, 1941	40,000	120,000	160,000	0.04
Japan	Mar. 31, 1939	1,367,958	—	1,367,958	1.89
Other Places in Asia*	Jan. 1, 1941	220,000	108,000	328,000	0.16
Total (Estimated as of Jan. 1, 1941)		1,710,000	290,000	2,000,000	0.19
AFRICA:					
Egypt	Jan. 1, 1940	67,983	—	67,983	0.30
Union of South Africa	Mar. 31, 1941	232,885	—	232,885	2.21
Other Places in Africa*	Jan. 1, 1941	146,000	1,460	147,460	0.11
Total (Estimated as of Jan. 1, 1941)		450,000	1,460	451,460	0.27
OCEANIA:					
Australia	Jan. 1, 1941	704,868	—	704,868	9.97
Hawaii	"	—	41,568	41,568	9.64
Netherland Indies	Jan. 1, 1940	48,321	4,492	52,813	0.08
New Zealand	Mar. 31, 1941	228,346	—	228,346	13.96
Philippine Islands	Jan. 1, 1941	2,504	31,419	33,923	0.20
Other Places in Oceania*	"	5,300	380	5,680	0.25
Total (Estimated as of Jan. 1, 1941)		992,000	78,000	1,070,000	1.06
TOTAL WORLD (Estimated as of Jan. 1, 1941)		17,385,815	26,803,854	44,189,669§	2.02

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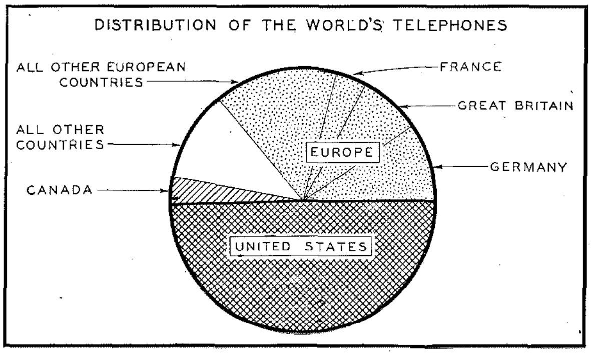
[1] Compiled by Chief Statistician's Division, American Telephone and Telegraph Company, and issued under the date April 1, 1942. "Owing to war conditions, official data for recent dates are not available for many countries. The statistics herein are the latest available from authentic sources."

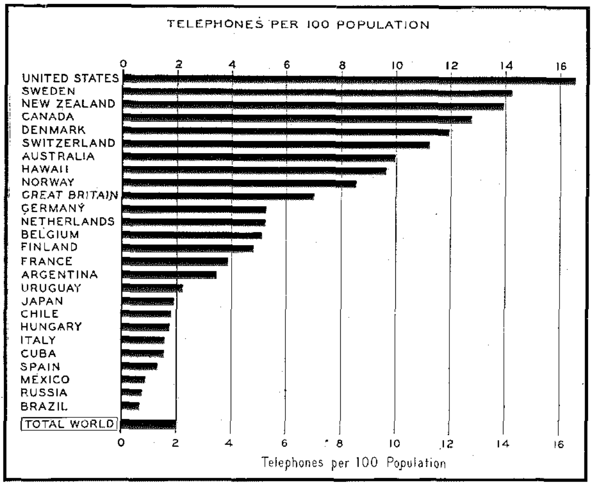
* Partly estimated. # As of January 1, 1942, there were 23,521,000 telephones in the United States.

† January 1, 1939. ¶ U.S.S.R., including Siberia and Associated Republics.

§ Approximately 58% of the total number of telephones in the world are estimated to be automatic or "dial" telephones, including, on January 1, 1941, some 11,700,000 "dial" telephones in the United States.

Telephone Statistics of the World—*continued*





Recent Telecommunications Developments

INTELIN HIGH TENSION APPLICATIONS.—Developments in the application of Styrene to high tension cables, such as described in previous issues of this journal,[1] are proving particularly important at the present time in view of the resulting saving in materials heretofore necessary for jointing and terminating cables. Such applications, offered in the U. S. A. under the trademark Intelin by the International Telephone and Radio Manufacturing Corporation, have permitted elimination of tin wiped joints for many services. Simultaneously, safeguards definitely prolonging the service life of cable installations have been provided.

In equipment potheads, the I.T. and R.M. is utilizing characteristics of the various styrenes to produce potheads about ⅓ the size and with about ⅓ the number of parts compared with previous types. Furthermore, the need for scarce non-ferrous metals and oil resistant gaskets is eliminated entirely; the amount of copper conductors required is reduced appreciably; and the pothead characteristics are improved. The importance of these applications will be evident when it is considered that electric power companies have over 20,000 miles of high tension cable serving the larger metropolitan centers in U. S. A. Industries, railroads and shipyards have about an equal amount.

Due to their initial lower cost and relative ease of effecting emergency repairs, overhead lines have been largely retained notwithstanding their considerably greater hazard and more numerous service interruptions. Underground installations, on the other hand, have not been entirely free from failures resulting in loss of power supply, sometimes for considerable periods. The greater safeguards provided by styrene applications will result in appreciable reductions in such outages and should accelerate the replacement of overhead lines by the less hazardous underground installations.

INTELIN HIGH FREQUENCY APPLICATIONS.—Intelin high frequency cables, recently developed, are capable of withstanding a temperature range from −30°C to + 85° C for prolonged periods without adversely affecting the cable, which remains flexible under these conditions. The Intelin insulation has a dielectric constant of 2.38 and a power factor at 100 megacycles of 0.0007. A minimum quantity of critical materials is required.

The cables are sheathed with a special plastic extruded covering resistant to oil, gasoline and water. Cables meeting a variety of service conditions can be produced.

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HIGH FREQUENCY MARINE TRANSMITTER, TYPE 167-A.—Following requirements specified by the Marine Division of the Mackay Radio and Telegraph Company, the Federal Telegraph Company has developed and is producing a new marine H.F. transmitter unique in the marine field. The frequency range is 2 to 24 mc with continuous coverage and micrometer adjustment in the oscillator control. While the transmitter is equipped for CW operation, it can be made available for both CW and MCW transmissions.

All controls are mounted on the front panel, thus enabling the operator to adjust the transmitter on any specified frequency within its range without recourse to any adjustments inside the cabinet. The circuit design is such that improper adjustment of the transmitter on any unwanted frequency harmonic is most unlikely. Hence choice of the proper frequency is positive and transmission on an erroneous frequency harmonic is practically impossible.

The transmitter is designed to operate on a voltage of 115 or 230 d-c and has an antenna power output of 200 watts on frequencies from 2 mc to 16 mc. The power output over the 16 mc to 24 mc range is in excess of 150 watts.

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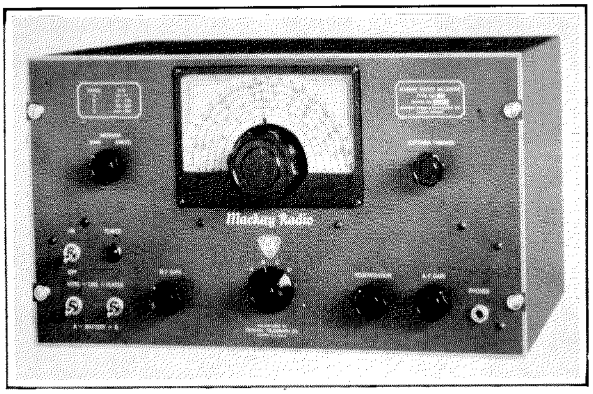
[1] "The Application of Styrene to H. T. Cable Systems," by T. R. Scott and J. K. Webb, *El. Com.*, Part I: Vol. 16, No. 2, 1937; Part II: Vol. 16, No. 3, 1937; Part III: Vol. 17, No. 1, 1938; Part IV: Vol. 19, No. 2, 1940; Vol. 19, No. 4, p. 141, 1941.

COMBINATION MARINE RECEIVER, TYPE 128-A. —The Federal Telegraph Company has developed and is manufacturing, in accordance with requirements specified by the Marine Division of the Mackay Radio and Telegraph Company, an IF–LF combination TRF marine receiver embodying some novel outstanding features. It employs the latest type of metal tubes and a circuit which is highly efficient and non-radiating. The frequency range is 15 kc to 650 kc and the dial is accurately calibrated in four separate bands with vernier adjustment.



A built-in power supply provides for plate voltage from either a-c or d-c 115 volt ship supply line. "B" batteries may be used instead, if desired. The standard receiver employs a 6 volt storage battery for the heaters of the tubes but operation of the heaters from an a-c line source can be provided on special order. On the front panel toggle switches provide for instantaneous changeover from the ship's supply line to auxiliary batteries. Consequently two requirements of the marine regulations are met in a single unit, i.e., a combined main and an emergency receiver.

A control knob mounted on the front of the panel provides for switching the receiver from the main to the emergency or auxiliary antenna.

PUERTO RICO.—The Porto Rico Telephone Company, associate of the International Telephone and Telegraph Corporation, is meeting the greatly increased demand for service through the installation of additional telephone equipment in central offices and elsewhere and through the use of carrier systems designed to increase the capacity of long distance circuits with substantial savings in copper and other strategic materials. The San Juan-Santurce metropolitan area is being converted from manual to automatic operation to meet increased service demands and provide more adequate facilities.

The Radio Corporation of Porto Rico, another I.T. & T. associate, has converted its broadcasting station, WKAQ, from 1 kw operating on 1240 kc to 5 kw operating on 620 kc. The higher power and change of frequency have resulted in complete coverage of the island.

As a result of increased traffic on the radio link between San Juan and Miami, twin channel, single sideband, short wave radio equipment will be installed in San Juan, Puerto Rico, in 1942. This will give Puerto Rico two high grade commercial circuits working directly with New York, capable of handling greatly improved point-to-point transmissions of broadcast programs.

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NEW MACKAY RADIO CIRCUITS.—The Honolulu-Chungking and SanFrancisco-Wellington radiotelegraph circuits, mentioned in the previous issue of this journal as under test, are now in operation. Other circuits recently inaugurated by the Mackay Radio and Telegraph Company are: New York-Honolulu; New York-Cairo; New York-Asuncion (Paraguay); San Francisco-Chungking; and San Francisco-Sydney/Melbourne.

INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION

Associate Companies in the Western Hemisphere

UNITED STATES OF AMERICA

International Standard Electric Corporation: *Manufacturer and Supplier of Communication and Other Electrical Equipment Through Licensee Companies Throughout the World; Exporter of Communication and Other Electrical Equipment*.....New York, N. Y.

International Telephone & Radio Manufacturing Corporation: *Manufacturer of Communication and Other Electrical Equipment*........East Newark, N. J.

Federal Telegraph Company: *Manufacturer of Radio Equipment*...........................Newark, N. J.

Commercial Cable Company: *Trans-Atlantic Telegraph Service*.....................New York, N. Y.

Commercial Pacific Cable Company: *Trans-Pacific Telegraph Service*.................New York, N. Y.

Mackay Radio and Telegraph Company: *International and Ship-Shore Radio Telegraph Services; Supplies, Operates and Maintains Marine Communication and Navigational Equipment*........ New York, N. Y.

All America Cables and Radio, Inc.
All America Cables and Radio, Inc. maintains 67 Company-owned telegraph offices in 23 countries and islands throughout Central and South America and the West Indies...........................New York, N. Y.

The Cuban All America Cables, Inc.: *United States-Cuba Telegraph Service*............New York, N. Y.

ARGENTINA

*Compañía Standard Electric Argentina: *Manufacturer of Communication and Other Electrical Equipment* ....Buenos Aires

Compañía Internacional de Radio (Argentina): *Radio Telephone Service*..............Buenos Aires

Sociedad Anónima Radio Argentina: *Radio Telegraph Service* ....Buenos Aires

Compañía Telefónica Argentina: *Telephone Operating System*.........................Buenos Aires

Compañía Telegrafico-Telefónica Comercial: *Telephone Operating System*...............Buenos Aires

United River Plate Telephone Company, Limited: *Telephone Operating System*...........Buenos Aires

BOLIVIA

Compañía Internacional de Radio Boliviana: *Radio Telephone Service* ....La Paz

BRAZIL

*Standard Electrica, S. A.: *Manufacturer of Communication and Other Electrical Equipment*
Rio de Janeiro

Companhia Radio Internacional do Brasil: *Radio Telephone and Telegraph Services*.....Rio de Janeiro

Companhia Telefonica Paranaense, S. A.: *Telephone Operating System* ....Curityba

Companhia Telephonica Rio Grandense: *Telephone Operating System* ....Porto Alegre

CHILE

Compañía de Teléfonos de Chile: *Telephone Operating System* ....Santiago

Compañía Internacional de Radio, S. A. (Chile): *Radio Telephone and Telegraph Services*.....Santiago

CUBA

Cuban Telephone Company: *Telephone Operating System* ....Havana

Radio Corporation of Cuba: *Radio Telegraph Service*
Havana

MEXICO

Mexican Telephone and Telegraph Company: *Telephone Operating System*................Mexico City

PERU

Compañía Peruana de Teléfonos Limitada: *Telephone Operating System*......................Lima

PUERTO RICO

Porto Rico Telephone Company: *Telephone Operating System*..............................San Juan

Radio Corporation of Porto Rico: *Radio Telephone Service and Radio Broadcasting*............San Juan

Associate Companies in the British Empire

*Standard Telephones and Cables, Limited: *Manufacturer of Communication and Other Electrical Equipment* ....London, England
Branch Offices: Birmingham, Leeds, England; Glasgow, Scotland; Cairo, Egypt; Calcutta, India; Pretoria, South Africa.

*Creed and Company, Limited: *Manufacturer of Teleprinters and Other Communication Equipment*
Croydon, England

International Marine Radio Company, Limited: *Supplies, Operates and Maintains Marine Communication and Navigational Equipment*..Liverpool, England

*Kolster-Brandes Limited: *Manufacturer of Radio Equipment* ....Sidcup, England

*Standard Telephones and Cables Pty. Limited: *Manufacturer of Communication and Other Electrical Equipment* ....Sydney, Australia
Branch Offices: Melbourne, Australia; Wellington, N. Z.

*Licensee Manufacturing and Sales Company of the International Standard Electric Corporation, New York, N. Y.

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